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EVALUATION OF THE IMPACTS OF ITS TECHNOLOGIES ON THE BORMAN EXPRESSWAY NETWORK

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October 1998

Indiana
Department
of Transportation

Purdue
University

Final Report

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Evaluation of the Impacts of ITS Technologies on the Borman Expressway Network

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16. Abstract

The Indiana Department of Transportation (INDOT) is currently implementing (or has implemented) several components of Intelligent Transportation Systems (ITS). This includes a mini Advanced Traffic Management Systems (ATMS) implemented on a three-mile stretch of the Borman Expressway to evaluate advanced non-intrusive sensor systems and the associated communication infrastructure for the installation of a full-scale ATMS on the 16-mile stretch of the Borman Expressway. Potential specific ITS technologies that are either being implemented or are being considered include pre-trip information, en-route information, variable message signs, and Hoosier Helpers. It is expected that the implementation of various ITS technologies on the Borman Expressway will result in improved traffic flow, lower travel times, higher average speeds, and improved safety and environment This study evaluated the impacts of these ITS technologies on mobility, air quality, and safety on the Borman Expressway and its vicinity. 1) Mobility-The performance of various ITS components under normal and incident conditions for the Borman Expressway Evaluation Network were simulated and the results were compared with the corresponding scenarios in the absence of these technologies. The results suggest that the network can accommodate the vehicles that divert from the Borman Expressway, indicated by the decrease in the overall network average travel time with increase in market penetration of information. Hence, providing en-route route diversion information to some users can result in signiticaut benefits in terms of travel time savings and congestion alleviation. 2) Air Quality - The performance of various ITS components under normal and incident conditions for the Borman Expressway Evaluation Network were simulated and the resulting HC, CO, and NO, emissions were compared with the emissions under a do-nothing scenario. The same network was used for air quality impact evaluation that was used for evaluating the mobility impacts of ITS. The results obtained from the simulation experiments indicated that significant improvement in air quality can be achieved by effective implementation of various ITS technologies under normal and incident conditions. One important trend observed from the results of these experiments was that the magnitude of reduction in mobile emissions was highest under incident conditions with link closure, and lowest under normal peak-hour conditions. 3) Safety - By testing the hypothesis that secondary crashes may take place as a diit result of primary incidents or traffic congestion, safety impacts were evaluated. Logistic regression modeling was used to predict the likelihood (risk) of a primary incident being followed by a secondary crash, using the "best" combination of primary incident characteristics. The resulting models suggested that the likelihood of a secondary crash occurring increases with an increase in the primary incident clearance time and with the involvement of a car, semi, or truck.

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IMPLEMENTATION REPORT

The results of the study have been presented to the Study Advisory Committee, which consisted of possible users of the information. It is expected that the results will be particularly useful to the Borman Second Phase project and to the Northern Indiana Regional Planning Commission in their planning studies. The INDOT Planning Division can also use the information for evaluating the future ITS projects in northern Indiana, as well as in other parts of the state.

PREFACE

Since its inception, the Gary-Chicago-Milwaukee freeway corridor has been a major transportation lifeline in America, both for freight movement and passenger mobility. Its importance to the regional economy is underscored by the fact that freight trucks constitute over 40% of the traffic during some time periods in a day. Several interstate highways pass through this region, which includes Northwestern Indiana. Due to natural barrier imposed by Lake Michigan, traffic from a number of major east-west interstate routes is funneled along a narrow corridor passing south of the lake. The constant heavy density of traffic in the region is highlighted by the Borman Expressway, a sixteen-mile segment of interstates SO and 94 (I-80/94) in Northwestern Indiana. The significant traffic load on the Borman Expressway is illustrated by the fact that 30% of the traffic during the day and 60% during the night is represented by large commercial vehicles. This compares to 15 percent found in typical Indiana Expressways. The route is a strategic part of the national system of interstate highways that is also a major artery linking local and regional travel in the tri-state, greater Chicago Metropolitan Area. I-80194 carries both east-west traffic and portions of the north-south traffic.

In Northern Indiana, I-90 competes directly with Borman Expressway, particularly for trips to and from central Chicago. However I-90 is a toll route, including the western portion of the Indiana Toll road and the Chicago Skyway. Tolls are relatively high, particularly on Chicago Skyway, and studies have indicated this aspect to be a significant barrier for using I-80/94 for trips oriented to and from the Chicago Loop, even it would typically save both mileage and travel time.

As a result of the orientation of interstate routes in Northwest Indiana and Northeast Illinois, coupled with the influence of Lake Michigan and tolls on I-90, traffic on the Borman Expressway has reached levels well beyond its theoretical capacity. I-80/94 carries over 140,000 vehicles per day in some segments, although only six travel lanes are presently available. In addition, as stated earlier, a substantial portion of traffic on the Borman Expressway consists of large commercial vehicles, further exacerbating traffic flow in the region.

In order to maintain a smooth flow of traffic on and around Borman Expressway, the Indiana Department of Transportation (INDOT) is currently implementing (or has implemented) several components of Intelligent Transportation Systems (ITS). This includes a mini Advanced Traffic Management Systems (ATMS) implemented on a three mile stretch of the Borman Expressway (HTMS, 1996) to evaluate advanced non-intrusive sensor systems and the associated communication infrastructure (Krogmeier et al., 1996) for the installation of a full-scale ATMS on the 16-mile stretch of the Borman Expressway. Currently under implementation, this ATMS aims at achieving seamless and efficient mobility in the region, either in an automated mode or through control by the Traffic Operation Center (TOC). It also aims at the efficient coordination and consistent integration of responses to traffic bottlenecks through the use of expert systems software to monitor the flow of information from Hoosier Helpers (highway patrol vehicles), Indiana State Police, INDOT and Illinois Department of Transportation (IDOT). It includes the surveillance system represented by advanced sensor technologies such as microwave and laser detectors, and communication systems represented by wide-area communication technology and spread spectrum radio, in addition to the information provision technologies. Currently, as part of the mini ATMS, Close Circuit Televisions (CCTV) are used through the installation of cameras at the Burr Street, Kennedy Avenue, and Cline Avenue interchanges on the Borman Expressway. This enables the TOC to get video updates of traffic conditions at these interchanges, and increases the accuracy of information provided to the Borman users by the TOC.

While the ATMS is represented by the various sensor/detector systems and associated communication infrastructure, the use of the time-dependent information on network traffic conditions generated by this system to enhance mobility and safety is based on several potential ITS advanced information provision technologies, called Advanced Traveler Information Systems (ATIS). On the Borman Expressway, the time-dependent information is stored at the Traffic Operations Center (TOC) which uses it to advise motorists of the Borman's current status, develop detour strategies when necessary, and/or provide route guidance. This is accomplished through several technological systems under consideration: (i) information provision to users using mechanisms such as Variable Message Signs (VMS) and Highway Advisory Radio (AM 530 radio channel), and (ii) incident management using the Hoosier Helpers program. Other potential information provision mechanisms include in-vehicle navigation systems, pre-trip information through telephone calls to an automated service in the TOC that updates network-wide traffic conditions, and en-route information through cellular phone calls.

Potential specific ITS technologies that are being either being implemented or are being considered include the following:

(i) Pre-trip Information: This information provision mechanism prior to the start of the trip provides users who access an automated service in the TOC the current best path to their destination. Other mechanisms include news media or HAR, which provide information on current traffic conditions in the network and/or route advisories.

(ii) En-Route Information: This capability exists for users who equip their vehicles with an in-vehicle navigation system or access the automated service en-route through a cellular phone. Such a capability allows users to make informed route switching decisions en-route when network conditions change during the trip.

(ii) Variable Message Signs: VMS, the most visible method of providing real-time traffic advisory and route guidance information, are being viewed as an integral part of the Borman freeway management process (HTMS, 1996). VMS can be permanently installed at key locations such as the intersections of major traffic corridors, freeways, and/or arterials. They can also be temporarily located (portable VMS) in the vicinity of incidents to manage traffic efficiently for the duration of the incidents. Placed at strategic locations, these signs can warn motorists of congestion that lies ahead due to an incident, special event, adverse weather, or other bottlenecks (work zones), and inform them of alternate diversion or detour routes.

(iv) Hoosier Helpers: The implementation of Incident Management Systems (IMS) on Borman Expressway is achieved by the Hoosier Helper program, using special highway patrol trucks equipped with advanced communications equipment, a video camera, a video monitor, and emergency equipment for stalled vehicles.

They have been identified as the system operator in the field and an essential player in the rapid detection, verification, response, and removal of incidents. In order to manage the incidents effectively and rapidly, the Hoosier Helper operators have specially equipped vehicles to operate key elements of the system directly from the vehicle. They have the capability to communicate with the Traffic Management Center (TMC); access the central system in the TMC; perform various system functions; log new incidents (including details such as the number of lanes affected and the expected duration); track existing incidents; and initiate response actions (including the notification of emergency and law enforcement agencies). The Hoosier Helpers patrol the Borman Expressway and a section of I-65,24-hours a day, seven days a week, assisting the highway users in that region.

It is expected that the implementation of various ITS technologies on Borman Expressway will result in improved traffic flow, lower travel times, higher average speeds, and improved safety and environment. This study investigated the impacts of these ITS technologies on mobility, air quality, and safety on the Borman Expressway and its vicinity. While only some of the above described technologies are planned for the near future, the impacts of the other technologies such as en-route navigation systems and automated service at the TOC were also evaluated to aid future ITS planning efforts in the Borman region.

This report has been divided into three sections. Details of the mobility impacts of ITS technologies are given in the first section, followed by the details of air quality impacts in the second section, and the safety impacts of ITS in the third section.

***Evaluation of ITS Impacts on Mobility*:**

The impacts of ITS on mobility were evaluated by simulating the performance of various ITS components under normal and incident conditions for the Borman Expressway Evaluation Network and comparing the results with the corresponding scenarios in the absence of these technologies. The components simulated were IMS, VMS, Pre-Trip Information, and En-route Information. The results indicate that these ITS technologies can result in great travel timesavings. It was observed that en-route information provides maximum travel timesavings when compared with the other technologies. Furthermore, the results suggest that the network can accommodate the vehicles that divert from Borman Expressway, indicated by the decrease in the overall network average travel time with increase in market penetration of information. Hence, providing en-route route diversion information to some users can result in significant benefits in terms of travel timesavings and congestion alleviation.

***Evaluation of ITS Impacts on Air Quality*:**

The impacts of ITS on air quality were evaluated by simulating the performance of various ITS components under normal and incident conditions for the Borman Expressway Evaluation Network, and comparing the resulting HC, CO, and NO, emissions with the emissions under do-nothing scenario. Same network was used for air quality impact evaluation, that was used for evaluating the mobility impacts of ITS. The ITS components simulated were IMS, VMS, and En-route Information. The results obtained from the simulation experiments indicated that significant improvement in air quality could be achieved by effective implementation of various ITS technologies under normal and incident conditions.

It was observed that for normal peak-hour conditions, maximum reduction in HC and CO emissions could be achieved by providing en-route information to the users, while maximum reduction in NO, emissions can be achieved by using the VMS. Incase of incident conditions, the maximum reduction in HC and CO emissions was seen from IMS implementation, while VMS still proved to be the most effective for NO, emissions reduction under these conditions. One important trend observed from the results of these experiments is that the magnitude of reduction in mobile emissions is highest under incident conditions with link closure, and lowest under normal peak-hour conditions.

***Evaluation of ITS Impacts on Safety*:**

The safety impacts of ITS were evaluated by testing the hypothesis that secondary crashes may take place as a direct result of primary incidents or traffic congestion. Logistic regression modeling was used to predict the likelihood (risk) of a primary incident being followed by a secondary crash, using the “best” combination of primary incident characteristics. The resulting models suggest that the likelihood of a secondary crash occurring increases with an increase in the primary incident clearance time, and with the involvement of a car, semi, or truck. The likelihood decreases during the winter months and on ramps or median shoulders. Given a better understanding of what contributes to secondary crash occurrence, various components of ITS technologies can be upgraded or adopted, and more effective relief strategies can be implemented to reduce secondary crash occurrence and improve roadway safety.

SECTION - I

EVALUATION OF ITS IMPACTS ON MOBILITY

1. INTRODUCTION

1.1 Motivation

Traffic congestion on the nation's highways is raising increasingly severe concerns in terms of travel delays, air quality and safety. In 1992 Traffic congestion accounted for $100 billion loss of national productivity yearly (Strategic plan U.S Department of Transportation 1992). Seventy two percent of miles traveled during the peak period in urban areas take place under congested conditions. The delays experienced on urban freeways are expected to increase 400% by 2005, if no improvements are applied to the existing system (Strategic plan U.S Department of Transportation 1992). Investment in additional infrastructure is no longer viable especially in urban areas, due to non-availability of land, the exorbitant costs, and the associated environmental & political concerns. In recent years, a two pronged strategy is being employed to address congestion. Demand management strategies aim at reducing travel demand (using approaches such as telecommuting, car-pooling, park and ride, etc.) and/or spreading the peak period demand (through ramp metering, congestion pricing, etc.). A more recent strategy aims at improving the efficiency of the existing infrastructure using technologies known as Intelligent Transportation Systems (ITS). ITS applies advanced and emerging technologies in such fields as information processing, communications, control, and electronics to surface transportation needs. ITS consists of six primary areas including Advanced Traveler Information Systems (ATIS), Advanced Traffic Management Systems

(ATMS), Commercial Vehicle Operations (CVO), Advanced Vehicle Control Systems (AVCS), Advanced Public Transportation Systems (ARTS), and Advanced Rural Transportation Systems (ARTS).

ATIS disseminate information to travelers through multiple information sources, including cable TV, digital broadcasts, Internet, kiosks, personal hand-held devices, VMS, HAR and in-vehicle navigation systems. ATIS can assist in pre-trip planning as well as enroute advisory and/or guidance. ATMS use surveillance systems to obtain real-time data on traffic conditions, and are used primarily for incident management and network level signal control.

CVO aims at improving efficiency and safety of commercial vehicle operations and transparency in regulations. It uses technologies such as automatic vehicle location, weigh-in-motion sensors, and automated vehicle classification devices. AVCS uses vehicle and/or road-based electro-mechanical and communication devices that enhance vehicle control by facilitating and augmenting driver performance, leading ultimately to automated roadways. ARTS are the advanced navigation and communication technologies applied to public transportation system operations to attract travelers to transit and ride-sharing modes. ARTS aims at improving highway safety by applying advanced technologies to rural networks.

Though ITS matured over the years, there are not many studies that evaluate the benefits from ITS technologies on quality of travel. There were some attempts to conduct field experiments called operational tests under the live conditions to evaluate the impacts of ITS. These operational tests are very expensive, time consuming and the output that comes out of these tests is of limited scope. Hence, operational tests are not very cost effective. Another way to evaluate ITS impacts is by using traffic simulation models. These models provide a cheaper and flexible tool to analyze the alternate control strategies of ITS. Extensive developments of traffic simulation models over the past few years have produced several effective programs to study the conventional traffic networks. Many of these models do not satisfactorily model the functional requirements of ATIS/ATMS. The main deficiencies of these models are (a) the lack of modeling of path-based traffic dynamics and (b) the lack of explicit representation of driver decisions such as route-choice under information. In the current study a Bayesian updating model is used to update traveler's perception of travel time from one day to the next in light of information provided by ATIS/ATMS and their prior experience. This model is incorporated in a framework, which includes a dynamic simulation-assignment model (DYNASMART) to simulate realistic ITS scenarios, and thus evaluate ITS impacts.

1.2 Objectives

The main objectives of this study is to use an appropriate simulation framework to simulate various ITS scenarios and evaluate the ITS impacts on the quality of travel. The various items that were addressed in this regard include:

(i) To use a day-to-day travel choice model and obtain paths that users use on a day-to-day basis between their respective O-D pairs.

(ii) Perform simulation experiments of various ITS scenarios using a dynamic simulation assignment model (DYNASMART). The paths obtained from the day-to-day travel choice model form the initial paths for the users.

1.3 Organization of this Section

This section is divided in to five chapters. Chapter 2 presents survey on Operational tests of ITS that are performed and literature review on simulation-assignment models that are viable for ITS. Chapter 3 discusses the study methodology. A brief discussion on the Simulator used in this study is presented in this chapter. Chapter 4 presents the framework of the simulation experiments conducted. The experimental setup is illustrated by discussing details of the study network, the loading pattern the assumptions on user behavior, and the characteristics of the simulation. Chapter 5 presents a detailed analysis of the simulation results and also discusses the overall conclusions, performance of the network on implementation of ITS projects.

2. LITERATURE REVIEW

This chapter presents a brief survey on various operational tests that are conducted in the U.S., followed by a literature ***review*** on traffic simulation-assignment models.

2.12.1 Operational Tests in US

Operational tests are those conducted in real-world environments under "live" traffic conditions (Mobility 2000, 1990). Because strong evidence on ITS technologies is still largely unavailable, decisions on major investments in ITS technologies depend largely on the results of these demonstration projects. In the last few years there were a number of operational tests in US to analyze ITS technologies and concepts, including:

- Pathfinder: This was a joint venture of FHWA Caltrans, and General Motors and represents the first operational test in the U.S. of an in-vehicle navigation system to improve traffic flow. It formed part of the $32 million SMART corridor Demonstration Program in Los Angeles. Twenty-five cars equipped with in-vehicle information systems received real-time information on incidents, highway construction, and traffic congestion, and alternate routes as they operated in the SMART corridor, with the objective of assessing the usefulness of real-time traffic information. The information was conveyed to the driver as an electronic map on an in-vehicle display screen or through digital voice. Because of the small-scale nature of the test, the program was more concerned with human factor issues.

- TravTek: This is a $8 million public/private partnership involving the city of Orlando, Florida, the Florida DOT, FHWA, American Automobile Association (AAA), and General Motors, in which 100 automobiles rented through AAA/Avis were equipped with an in-vehicle TravTek device to provide drivers with traffic congestion information and tourist information. A traffic management center in downtown Orlando collected real-time traffic information for a 750 square mile by using cars themselves as probes, as well as through 50 police agencies, in-road sensors and surveillance cameras on I-4, traffic signal monitors and radio broadcasts. The one-year demonstration project was completed in March 1993. The objective was to attempt to determine the market penetration required to use information provided by the vehicles (as probes) as a reliable basis for real-time information, by using a simulation model to extrapolate from the experimental results.
- HELP/Crescent: The $25 million HELP/Crescent is a CVO demonstration project aimed at creating “transparent borders” for interstate trucking to avoid delays at weighing stations, and enhance productivity and safety. HELP (Heavy Vehicle Electronic License plate Program) involves about 2,000 trucks in a test area covering 35 sites that formed a rough crescent shape in six Western states (Washington, Oregon, California, Arizona, New Mexico and Texas). Its aim was to design and test an integrated heavy-vehicle monitoring system using Automatic Vehicle Identification (AVI), Automatic Vehicle Classification (AVC), and Weigh-In-Motion (WIM) technologies. The Crescent project represented the demonstration phase of HELP. Each truck entering the system was automatically identified and classified by means of

an electronic license plate, and the truck weight was determined using WIM technology. A central controller processed the information and the truck was allowed to bypass other sites along its route.

- Advantage I-75: The Advantage I-75 program is also a CVO demonstration project. This public-private joint project was organized in 1990 to reduce congestion and enhance safety and efficiency along one of the busiest trucking corridors in the United States. The project was expected to involve up to 4,000 trucks. Six states (Florida, Georgia, Kentucky, Michigan, Ohio, and Tennessee) and the province of Ontario in Canada were the initial participants in this project. The Advantage project took a decentralized approach, in which transponder-equipped trucks contain electronic information packets detailing their size and weight, and pre-clearance decisions at downstream stations were based on the information obtained upstream. Thereby, each state retained its regulatory authority and procedures relative to commercial vehicles and their operations, and timesavings were obtained by bypassing some weigh stations.
- ADVANCE: The ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) project was a large scale ITS demonstration project. The Illinois DOT, Motorola, Inc., the Illinois Universities Transportation Research Consortium the FHWA, and a large fleet of private and commercial vehicles, was equipped with in-vehicle navigation systems and served as traffic probes, in a 300 square mile area in Chicago’s northwest suburbs. The vehicles used differential GPS navigation as well as dead reckoning and map matching to navigate their way through the study area. Under the ADVANCE project, trip time information was to be transmitted to vehicles in a

quasi real-time. The on-board electronic navigation system was to compute a driver's best route to the desired destination, using information on traffic conditions and driver preferences.

- Guidestar: Guidestar is a $119 million, five-year ITS program involving the Minnesota DOT, University of Minnesota, and FHWA to bring together a number of on-going operational ATIS/ATMS efforts with a wide range of ITS technologies aimed at reducing congestion and enhancing safety throughout the state. The bulk of the effort has been directed to advanced traffic management for freeways and arterials. The system covered the entire Minneapolis-St. Paul metropolitan area and was intended to be linked to the central traffic management center through a new fiber-optic network. The program emphasized the gathering and distribution of traffic information for use by travelers and controllers, and included the development of the Autoscope video imaging vehicle detection system.
- FAST-TRAC: This project in Oakland County, Michigan aimed at integrating ATMS and ATIS systems to direct equipped vehicles away from congested areas and enhance mobility and safety in these areas. FAST-TRAC (Forum for Advanced Safe Travel through traffic Routing and Advanced Control) used video image processing to gauge traffic conditions, and adjust signals in response to the congestion **situation.** It is a joint public/private sector venture involving Michigan DOT, Siemens Automotive, General Motors, Ford, Chrysler, Oakland county, and the city of Troy. The project has had a long-term goal of equipping 1000 intersections with automated traffic control systems,

and it anticipated 200 Ali-Scout beacons communicating with up to 5000 equipped vehicles, for "total ATIS-ATMS integration”.

The other ITS Operational tests that are planned or already underway include SMART Corridor, PATH, INFORM, TRANSCOM, Smart Card and Smart Commuter projects. Operational tests however, are very expensive, time consuming and may not be applied to test the feasibility of new ITS technologies. The other way to evaluate the impacts of ITS is by performing simulation experiments. Simulation provides a cheaper and powerful tool to explain various complex variables in the urban traffic system. Moreover simulation can also be used to study the feasibility of new ITS technologies.

2.2 Traffic Simulation-Assignment Models

The primary function of traffic simulation models is to support the analysis and design of control strategies for the efficient operation of traffic systems. In addition to the ability to represent the control strategy itself, the simulation model needs to be able to describe the behavior of traffic in response to the control. All the models that were developed till 1986 (starting from 1980) to describe day-to-day dynamics in a transportation network had a limited scope. All these models are developed for a network with one O-D pair. The model proposed by Ben-Akiva et al. was further extended (Vythoulkas 1990) to the case of general networks. In the models proposed by Ben-Akiva et al. and Vythoulkas, the evolution of traffic pattern on the network from day to day is derived from a Markovian model assuming that the system reaches a steady state. However, the existence and uniqueness of the steady state was solely based on simulation results. In a two stage Bayesian updating model (Jha 1996), no a priori assumption is imposed on the final state of the network vis-a-vis equilibrium or steadiness. This allows one to represent the travel behavior at a finer level of detail. A stochastic process approach (Cascetta and Cantrella 1991) for modeling day-to-day and within day dynamics has also been proposed. Again a Markovian model represents the evolution of the traffic pattern from one day to the next. In this study, it was shown that under a set of assumptions the network reaches a unique steady state. One of the key assumptions in this study implies that users' current route and departure time choices do not affect their future choices, which is not a realistic assumption. The Bayesian updating model (Jha 1996) explicitly accounts for the effect of the learning process i.e. users learn from their experience as well as from traffic information.

A number of simulation studies have been carried out to evaluate the impact of various information strategies on network performance using diierent user behavioral models. Most of these studies consider users' accessibility to ATIS as an indicator variable. By modeling accessibility to ATIS as an indicator variable, the variation across users in terms of how they respond to ATIS is not captured. Some of the studies performed to model the impact of ATIS on network performance are listed here. Users route choice dynamics in the case of lane closures was studied in a simulation environment (Mahmassani and Jayakrishnan 1988). The results showed that providing real time in-vehicle information to users can lead the network to reach a steady state at a faster rate than under the no-information case. In an another related study on day-to-day dynamics, (Mahmassani 1990) it was found that under different information strategies, the network reached a steady state at diierent rates. The issue of day-to-day dynamics in the presence of ATIS was studied analytically (Friesz et al. 1994) and it was shown that under complete or incomplete information, a network would reach a steady state. In this study it is assumed that all users who have access to ATIS behave in the same way. There is very little work done on capturing the dynamics of users' travel time perceptions. A weighted average approach was suggested (Ben-Akiva et al. 1991) to represent driver's perceived travel times as a function of the historic perceptions and the information travel time. This information model assumes that travel times are deterministic variables and hence doesn't account for stochastickity in drivers' perceptions of travel times.

Users' choices of route and departure time are primarily governed by perceived travel times. Hence, it is important to model the information processing and perception updating mechanism of users. Further more, the variance of the perceived travel time, which represents the driver's confidence in his/her perception is an important factor in the choice process. In the Bayesean updating model (1996) the driver's confidence in the perceived travel time is explicitly modeled and this factor is used in the choice model. A detailed description of Bayesian updating model (Jha 1996) is presented in section 3.2.

3. METHODOLOGY

The simulation approach focuses on the movements of vehicles according to established traffic flow relations. The vehicles in this approach are either moved individually or in the form of packets. Based on the level of detail at which a traffic system is modeled, the simulation models are classified as Microscopic (movements of the individual vehicles are traced through a network), Macroscopic (treats vehicle movements as progressions of vehicle platoons) and Mesoscopic (has characteristics of both Micro and Macro models). Extensive development of traffic simulation models over the past 20 years has produced several effective programs (NETSIM, INTRAS, TRANSIT, PASSER, TEXAS etc.) to study conventional traffic networks. Such simulators do not support the functional requirements of ATIS/ATMS. The two main deficiencies of these models are (a) lack of path processing capability and (b) the lack of explicit representation of driver decisions. With the advent of ITS technologies, researchers began to develop simulators that could potentially support the requirements of ATIS/ATMS. Some of the commonly known simulators that support ITS technologies are DYNASMART (Jayaloislman et al. 1994), INTEGRATION (VanAerde 1992) and CONTRAM (Leonard and Gower 1982). These are developed on the basis of the vehicle movement approach. The advantages of this approach are two fold: from a practical point of view, this approach can represent tragic flow more realistically. This is because no unreasonable assumptions are needed to formulate the problem. Secondly, in this approach, it is possible to model driver behavior at a finer level of detail, because each vehicle can be treated independently.

CONTRAM (Leonard and Gower 1982) is a model developed in United Kingdom. CONTRAM takes groups of vehicles (in 'packets') and routes them through the network along time-dependent minimum travel time paths. It can model traffic signals, roundabouts, give-way junctions and bottlenecks, and includes 'horizontal' queuing so that queues at one junction can block-back along a road and restrict the capacity of upstream junctions. Several classes of vehicles can be included (cars, trucks and buses).

INTEGRATION model was conceived during the mid 1980's as an integrated simulation and traffic assignment model (Van Aerde , 1985; Van Aerde and Yagar, 1988a and b; Van Aerde and Yagar, 1990). INTEGRATION is a fully microscopic simulation model, as it tracks the lateral as well as longitudinal movements of individual vehicles at a resolution of up to one deci-second. It combines various microscopic details of car-following, lane changing and gap acceptance behavior with such macroscopic features as traffic assignment, coordination delay and speed-flow relationships. In simulation, a vehicle starts off on the best path between its O-D and after reaching a node it checks for the best path from that node to its destination and chooses that path. The process is repeated until it reaches its destination. This case falls under 'myopic' user behavior (a more detailed description is given in sub section 3.1.11).

The above two models assign users to the best available path between their origin and destination. These models have a limited behavioral basis, and little or no ability to incorporate realistic behavioral rules for the response of the drivers to information/guidance. This is inadequate in the ITS context where a realistic

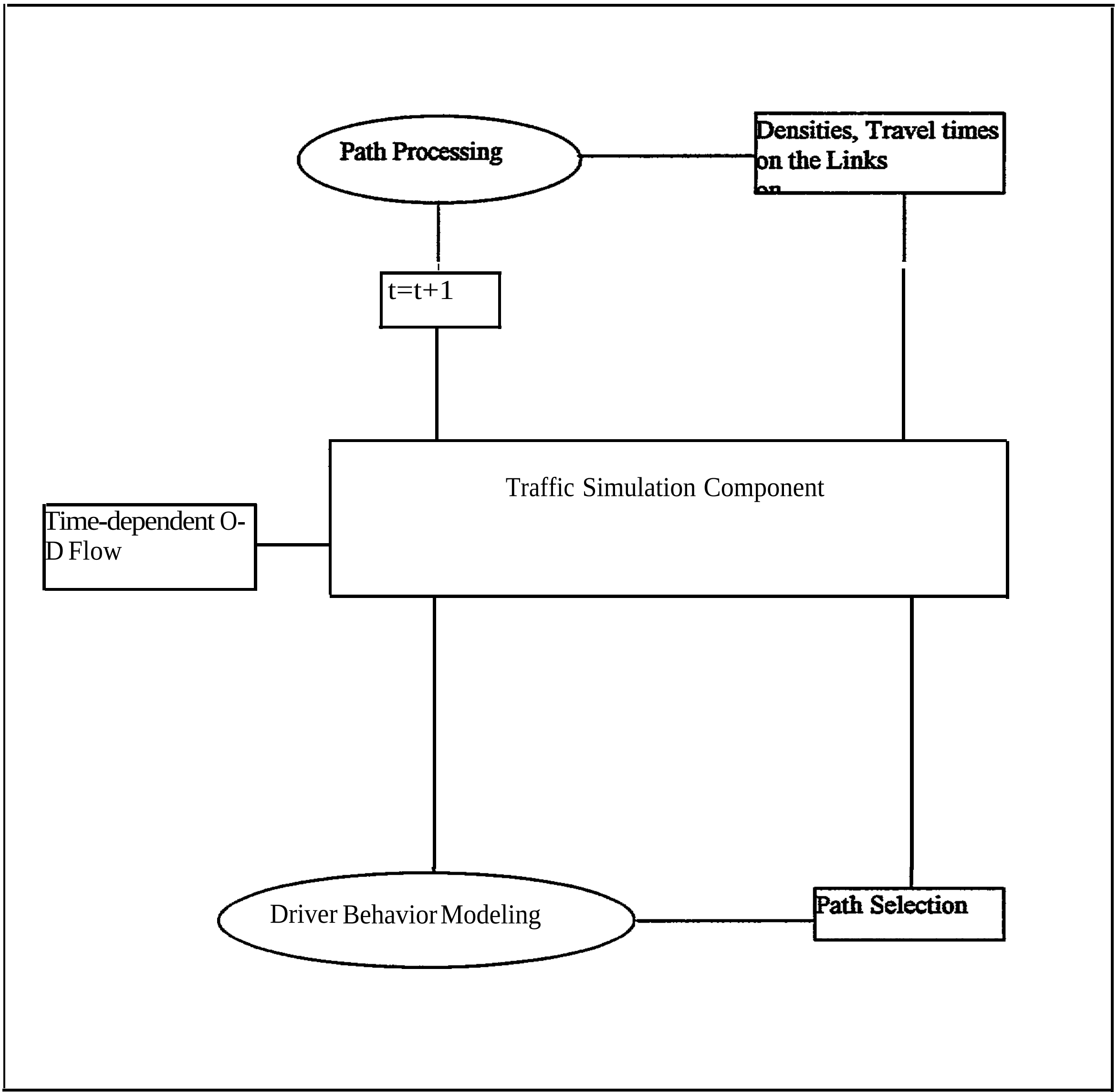

Figure 3.1. DYNASMART model structure

representation of user behavior is required in order to assign an user on a particular route. One of the currently available simulation models that has potential to do this is DYNASMART (Dynamic Network Assignment Simulation Model for Advanced Road Telematics). DYNASMART is a mesoscopic dynamic network assignment-simulation model for ITS applications developed at the University of Texas at Austin. It models traffic patterns and evaluates overall network performance under real-time information systems, for a given network congifuration, traffic control systems and given time-dependent OD demand pattern. The modeling approach integrates a traffic flow simulator, a network path-processing component, user behavior rules and information supply strategies. The conceptual model is shown in Figure 3.1.

4. SIMULATION EXPERIMENTS

This chapter presents a framework for the simulation experiments conducted for this study. It also includes experimental setup for all the experiments followed by a detailed discussion on the design of simulation experiments conducted on Borman expressway evaluation network. Various ITS scenarios were simulated and the performance of traffic network is analyzed under these scenarios. The main performance measure that is looked at is the average travel time. The results and the detailed analysis are presented in chapter 5.

4.1 Framework for the Evaluation of I.T.S Impacts

In the current study DYNASMART and the day-to-day travel choice model were integrated to simulate various ITS scenarios. Fii the day-to-day travel choice model was run for 25 days and the paths of various users on 25” day were stored in a file. These paths were assumed to be the paths that users take on a day-to-day basis after gaining sufficient experience about the paths between their respective O-D pairs. These paths were read by DYNASMART and were assigned as the initial paths to users in the appropriate simulation experiments. The framework is shown in Figure 4.1.

4.2 Experimental Set-on

This section discusses the details of network configuration and traffic characteristics, a description of the experimental set-up.

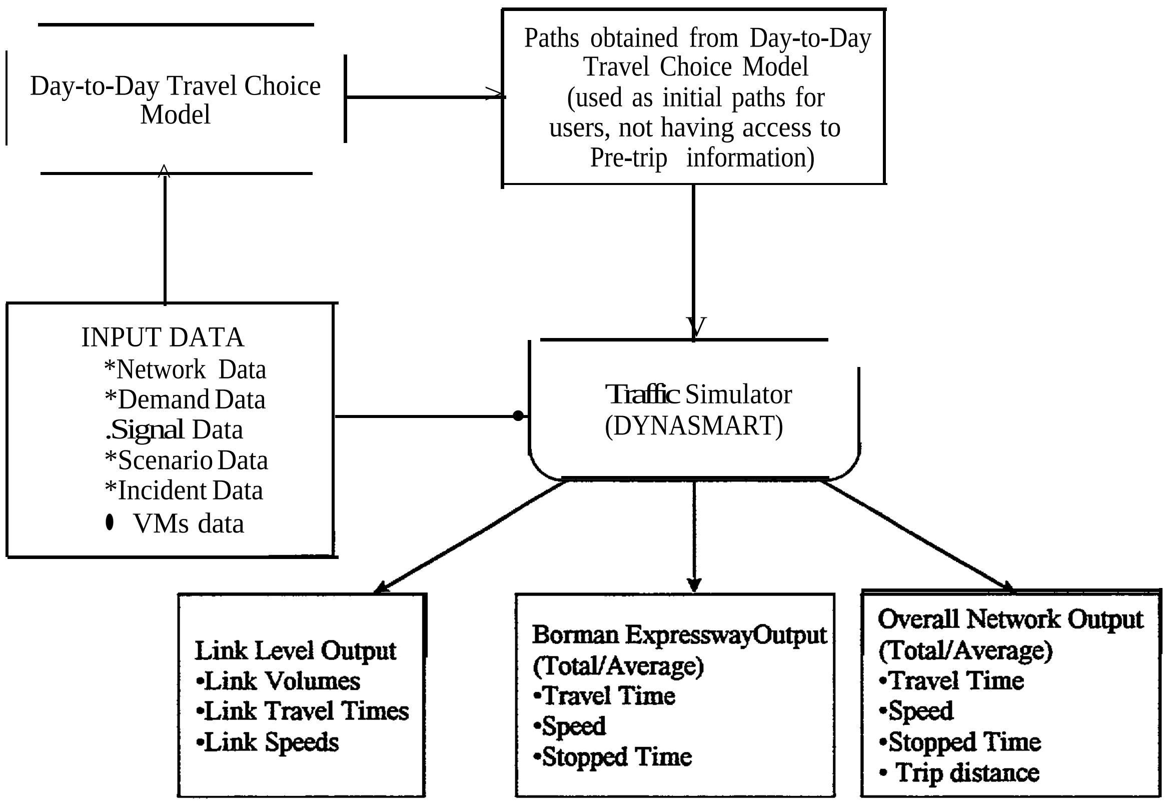

Figure 4.1 Framework for lTS impacts evaluation

4.2.1 Network Configuration and Traffic Characteristics

The network consists of Borman Expressway, I-90 toll road, I-65 and the surrounding arterials as shown in Figure 4.2. The network consists of 197 nodes and 458 links. The network is divided into 43 zones with 43 origin zones and 43 destinations. All the characteristics of the links (link lengths, number of lanes, link capacity, free flow speed) were collected and the corresponding input tiles were prepared. The maximum bumper to bumper and jam densities are assumed to be 260 vehicles/mile and 160 vehicles/mile respectively for all the links of the network. The network has 78 nodes with actuated signal control and the rest have no signal control.

4.2.2 Experimental factors

- O-D matrix: The origin destination demand for 43 origin (zones) and 43 destination (zones) is obtained fiom an another project entitled Interstate 80/94 Congestion Relief study (1994). The O-D matrix obtained from this project is adjusted to suit the study area.
- Loading patterns: The loading profile that is considered is as shown in Figure 4.3. The loading impacts the network with relatively large number of vehicles over a 20-minute period that is preceded and succeeded by low levels of loading as shown in Figure 4.3. It is assumed that this represents a typical peak hour loading pattern. The vehicles are generated over a 60-minute period, which includes a 5-minute startup generation time in order for the network to be loaded with reasonable number of vehicles.

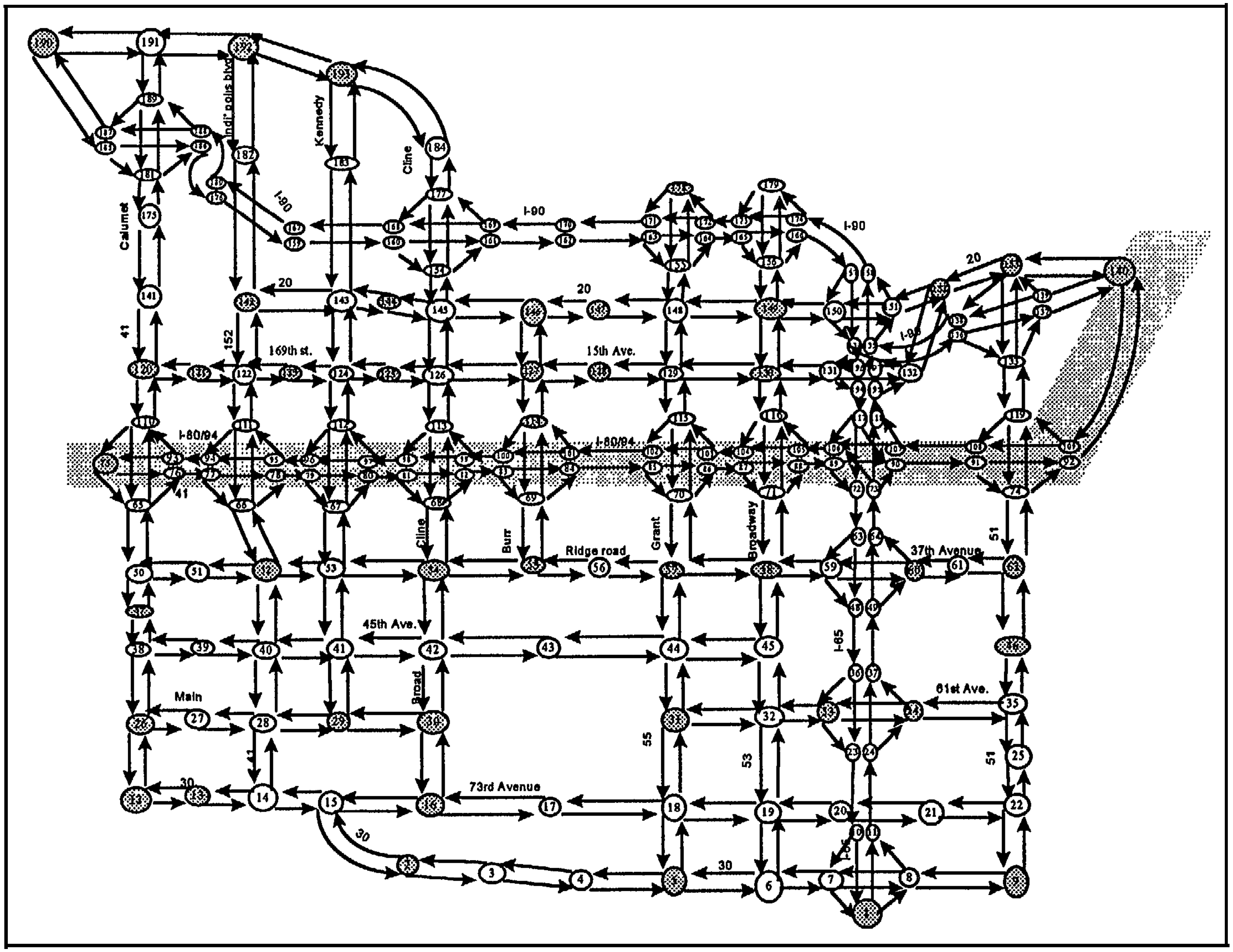

Figure 4.2 The study network

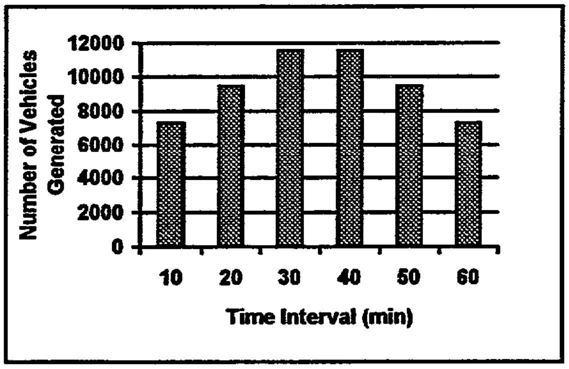

Figure 4.3 Loading Profile

4.3 Design of Experiments

Four ITS technologies were considered to evaluate their impacts on travel quality. These are (1) Pre-Trip Information, (2) En-route Information (3) Incident Management Systems (IMS), and (4) Variable Message Signs (VMS). Also two hybrid scenarios (combination of technologies) were simulated. These are (a). Pre-trip and en-route information and (b). Pre-trip, en-route and VMS. A base case is first simulated to replicate the current travel pattern in the network. The base case is then used as the reference for all other simulation scenarios. All ITS technologies were simulated for three different scenarios. The scenarios are described below:

Scenario I : Normal afternoon peak period conditions (3:00pm to 4:00pm).

Scenario II : Peak hour conditions (3:00pm to 4:00pm). An incident on west bound Borman expressway link between Kennedy and Indianapolis blvd. causing a lane closure (50% reduction in link capacity) for a duration of 50min. Start time of the incident is 3:05pm. In a study conducted by Minnesota DOT, it is found that blockage of a single lane can reduce capacity of a three lane freeway by over 50%.

Scenario III : Peak hour conditions (3:00pm to 4:00pm). An incident on west bound Borman expressway link between Kennedy and Indianapolis blvd. causing the link closure (100% reduction in link capacity) for a duration of 50min. Start time of the incident is 3:05pm.

4.3.1 Base Case

Assumptions:

The base case represents the 1996 travel pattern in the study area with out any ITS technologies.

- A user after gaining sufficient experience (over few days) in the network, stabilizes on a particular route between his/her origin and destination. These paths are obtained from the day-to-day travel choice model by running the model for 25 days and storing the paths on 25th day.
- Users do not switch en-route.

4.3.2 Pre-Trip Information

Assumptions:

- The users get information about the best route between their respective origin and destination. The sources of information include radio, cable TV, kiosks, intemet, traffic control center etc.

- Users do not switch en-route.
- Certain fraction of users are assumed to have access to pre-trip information.
- The users who do not have access to pre-trip information stay with their normal paths.

Six diierent values were considered for the percentage of users with pre-trip information. The values were 0%, 20%, 40%, 60% 80%, 100%.

4.3.3 En-route Information

Assumptions:

- The users get a periodic update about the best route between their respective origin and destination. The information is obtained by in-vehicle guidance system, contacting traffic control center by cellular phone, Highway Advisory Radio (HAR) etc.
- Users switch en-route in a bounded rational manner. The mean relative indiierence band is assumed to be fixed throughout the experiments at a value of 0.2.
- Certain fraction of users are assumed to have access to en-route information.
- The users who do not have access to en-route information stay with their normal paths and do not switch en-route.

Six diierent values were considered for the percentage of users with en-route information. The values were 0%, 20%, 40%, 60% 80%, 100%.

4.3.4 Incident Management Systems (IMS)

Assumptions:

- A user after gaining sufficient experience in the network, stabilizes on a particular route. These paths are obtained from the day-to-day travel choice model.
- Users do not switch en-route.
- The incidents are managed through a program called Hoosier Helpers project.

The incidents are detected, and cleared in a reasonable amount of time. IMS is assumed to reduce the incident duration by certain amount and three different values were considered for this value, namely **10min, 20min** and 30min.

4.3.5 Variable Message Signs (VMS)

Assumptions:

- VMS provide down stream traffic conditions and information on alternate routes.
- 10 VMS are installed in the network. 8 VMS on Borman Expressway, 4 on east bound and 4 on west bound, 2 on I-65. The VMS locations are shown in Figure 4.4.
- The initial paths the users take are same as in the base case.
- Certain fraction of users who travel on the link on which VMS is located will be willing to divert to alternate routes if there exists a better path than the

current one (myopic switching). Note that the switching mechanism is myopic in all the experiments unless stated as different. Other users are assumed to stay with their normal route.

Six different values were considered for the percentage of users willing to divert because of VMS. The values were 0%, 20%, 40%, 60%, 80%, and 100%. However, it is known that 50% of the Borman users are Indiana residents and it may not be realistic to assume more than 50% of the users divert because of VMS.

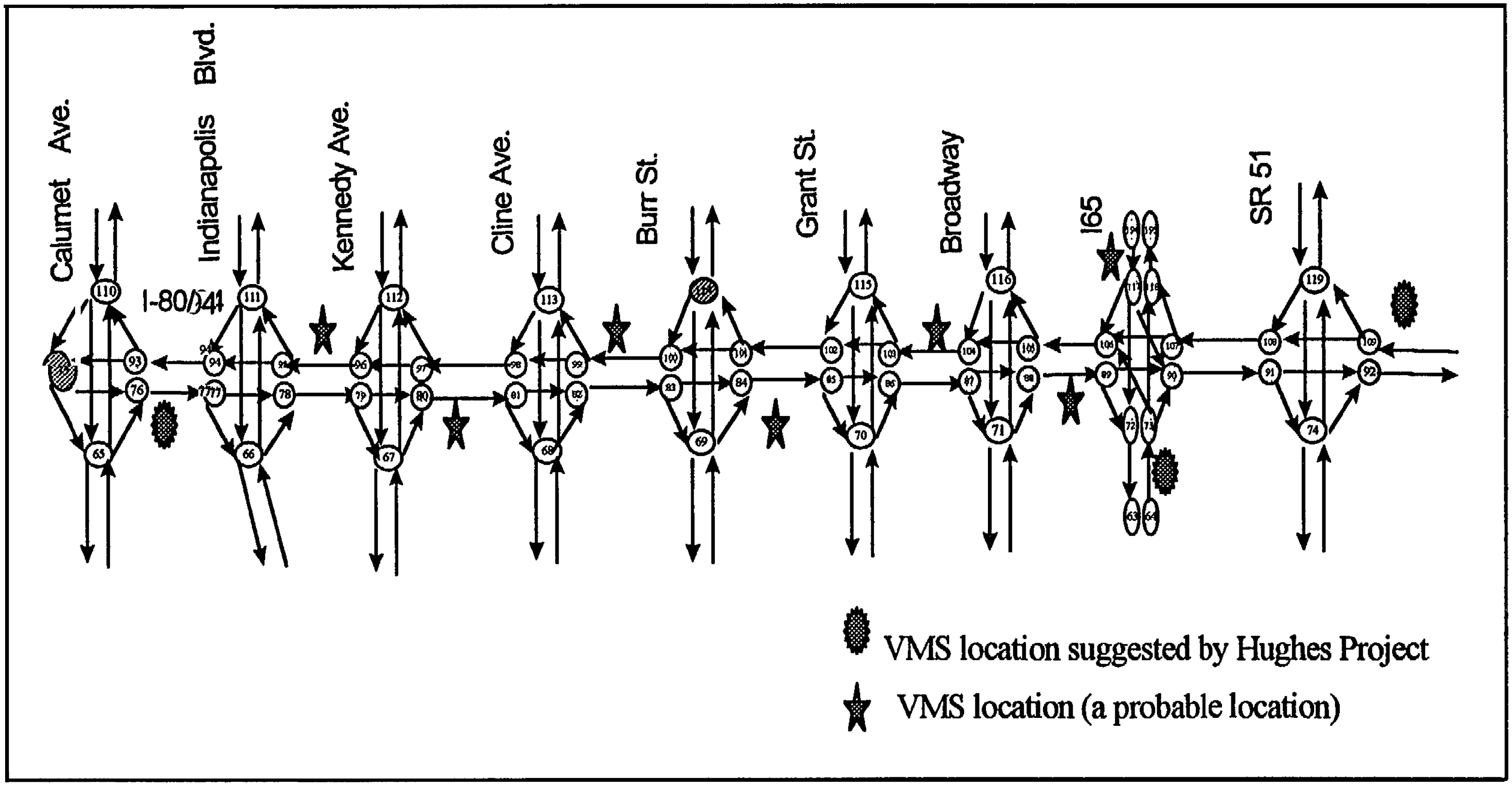

Figure 4.4 VMS locations

5. IMPACT ASSESSMENT

This chapter presents a detailed analysis of the simulation results followed by conclusions drawn from these results. The results are presented for various experiments described in Chapter 4.

5.1 Analysis of Simulation Results

A detailed description of the simulation results for the three scenarios is presented in this section.

5.1.1 Scenario I (Normal afternoon peak period)

The results for Pre-Trip information are shown in Figure 5.1. The results for tbe base case can also be seen in Figure 5.1. The case of 0% of the users having access to Pre-Trip information corresponds to the base case. As can be seen from the graph, the base case performs worst on both Borman expressway and overall network. The Borman expressway performs best when 40% of the users have access to Pre-trip information. The percentage travel time savings for diierent levels of accessibility of Pre-Trip information is shown in Figure 5.2. 100% of users having access to Pre-Trip information is worse than the base case. As the percentage of users with pre-trip information increases beyond a certain value (40%) the performance on Borman goes down. This is because as more and more users have access to Pre-Trip information, they choose the best routes and hence these best routes get congested. At the network level the travel time savings keeps on increasing with increase in market penetration of information. This is because the unexplored routes (in case of no information) are being used with more and more information. Note that the network travel time savings includes Borman also. Also, Borman west bound is initially less congested (no information case) when compared with that of east bound. With the increase in market penetration of information the west bound is assigned to more and more users and at the same time users on east bound are diverted to alternate paths.

The results for en-route information are shown in Figure 5.3. The Borman expressway performs best when 40% of the users have access to en-route information. The performance of the network with fraction of users with information follows similar trend as in pre-trip information case. The same explanation as in pre-trip case may be given for this trend. Note that the average travel times on east bound and on west bound Borman are closer relative to pre-trip information. This is because with enroute information users can switch enroute to alternate paths but this is not possible with pre-trip information. The percentage travel time savings with en-route information is shown in Figure 5.4. The benefits from en-route information is relatively higher when compared with that of Pre-Trip information, because en-route enables users to switch to better routes during the trip.

The average travel time with VMS is shown in Figure 5.5. The average travel time decreases on Borman with the percentage (until 20%) of users willing to divert due to VMS. Beyond 20% the Borman becomes less congested and hence people may not divert. Note that users divert due to VMS only if there exists a better path (however small the gain may be) than the current path. Note that the average travel times on east bound and on west bound Borman are almost same with VMS. This is because users divert to alternate routes in a myopic fashion.

The average travel time with various technologies is presented in Figure 5.10. The average travel time savings over the base case is shown in Figure 5.11. The travel time savings is best achieved using en-route information for the network. VMS gives slightly better performance than en-route information on Borman because users are assumed to switch in a myopic way. As of now it is not very clear as to how an individual reacts towards diierent information sources. If we assume users switch in a bounded rational manner due to VMS then Borman average travel time goes up slightly. The network's average travel time also goes up slightly. VMS as expected doesn't do well for the entire network since VMS are installed only on Borman. En-route is better than pre-trip information and VMS as users can divert at every node (where diversion is possible). The hybrid scenarios (pre-trip and en-route info., pre-trip, en-route info. and VMS) perform slightly worse than en-route alone. This is because, under these scenarios more users have access to information (some kind of information may be pre-trip alone, enroute alone or both) thus congesting the best routes and hence the slight decrease in % travel time savings.

5.1.2 Scenario II (Lane closure)

The average travel time with the VMS is shown in Figure 5.6. When a lane is closed the average travel time on westbound Borman remains higher than that of east-bound Borman. This is expected since the incident is on westbound Borman. Here also if 20% of the Borman users divert, then Borman remains an attractive route.

The reduction in average travel time with the reduction in incident duration is shown in Figure 5.8. It can be seen that the average travel time decreases with a reduction in incident duration. Also, the rate of decrease in average travel time is much higher for Borman when compared to the entire network. This is again anticipated because of the incident's location.

The average travel time with various technologies is presented in Figure 5.12. The average travel time savings over the base case is shown in Figure 5.13. The hybrid scenario, pre-trip and en-route information performs best because during incident conditions, the higher the number of users with information the better is the network performance. The users with information can avoid the incident route and hence less overall delay. IMS provide around 13% travel time savings if the incident duration is reduced by 20min. This is smaller when compared with the savings from pre-trip, en-route or VMS because in the IMS scenario, users who are already on the west bound Borman will not divert even though they see an incident. In all other scenarios there is a possibility to avoid incident route. Again Pre-trip information alone is giving significant amount of travel time savings. when compared with that of enroute information. This shows that just by informing the users who are about to start their trip during the incident duration one can achieve considerable reduction in travel delays. The same is observed with link closure scenario also.

5.1.3 Scenario II (Link closure)

The average travel time with the VMS is shown in Figure 5.7. When a link is closed the average travel time on west bound Borman remains much higher than that of east bound Borman. Here, the greater the percentage of users willing to divert due to VMS the better is the petiormance on Borman. This is expected because the link is completely closed for 40 min and hence westbound Borman will not be attractive during that time.

The reduction in average travel time with the reduction in incident duration is shown in Figure 5.9. It can be seen that the average travel time decreases with a reduction in incident duration. Also, the rate of decrease in average travel time is much higher for Borman when compared to the entire network. This is again anticipated because of the incident's location.

The average travel time with various technologies is presented in Figure 5.14. The average travel time savings over the base case is shown in Figure 5.15. The en-route alone and the hybrid scenario, pre-trip and en-route information performs best because during incident conditions, the higher the number of users with information the better is the opportunity to switch and hence better network petiormance. IMS provide around 34% travel time savings if the incident duration is reduced by 20 min. Note that this is very high when compared with that of Iane closure scenario.

5.2 Conclusions

- The above results suggests that there exists an optimal value for the fraction users with information at which the network performs best. This is true for any source of information. This optimal fraction may be different for different sources of information. Also this may vary with traffic conditions (congestion level), network conditions (incidents etc.).

- The en-route information provides maximum travel time savings in all the scenarios, when compared with the other technologies. But, the excess benefits when compared with that of pre-trip information is not much. Moreover pre-trip information is relatively easy to implement and is an immediate possibility when compared with that of enroute information.
- The behavior of users towards various information sources is not very clear at this point of time. A detailed field survey may be conducted to know how users weigh different information sources.
- The various results indicate that ITS projects when properly implemented can result in great travel time savings.
- There exists enough room in the network to accommodate the vehicles that divert from Borman expressway. This can be clearly seen from the fact that the overall network average travel time decreases with increase in market penetration of information.
- This study also demonstrates how one can realistically simulate the network tragic conditions under various scenarios with out actually conducting the high cost operational tests.

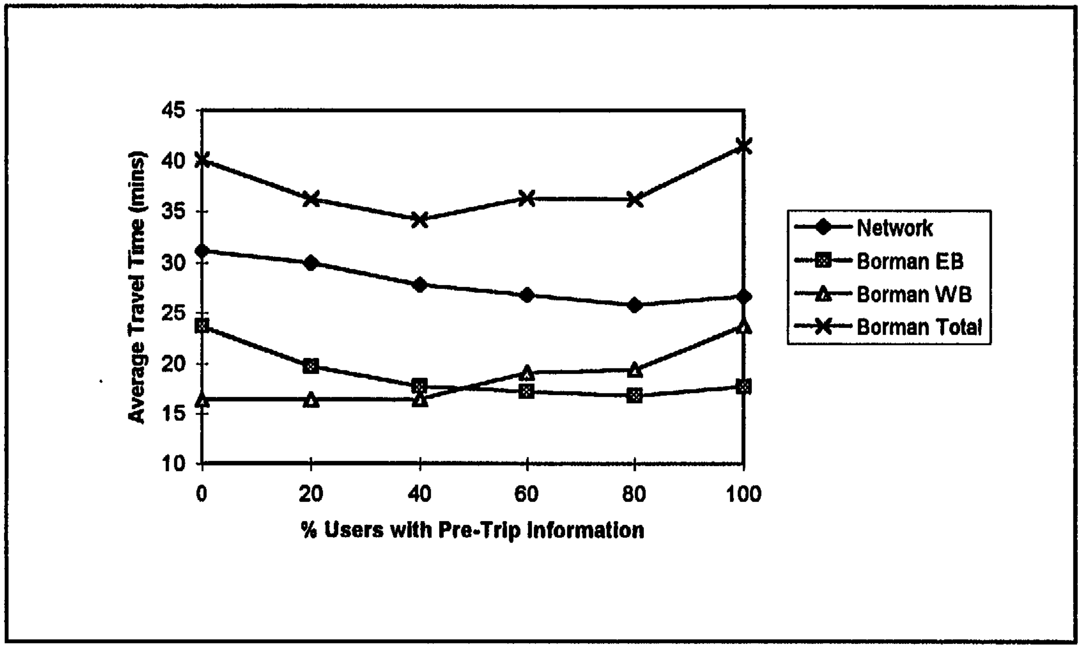

Figure 5.1. Scenario-I (Normal Afternoon Peak Period) : Variation of average travel time with the accessibility of pre-trip information.

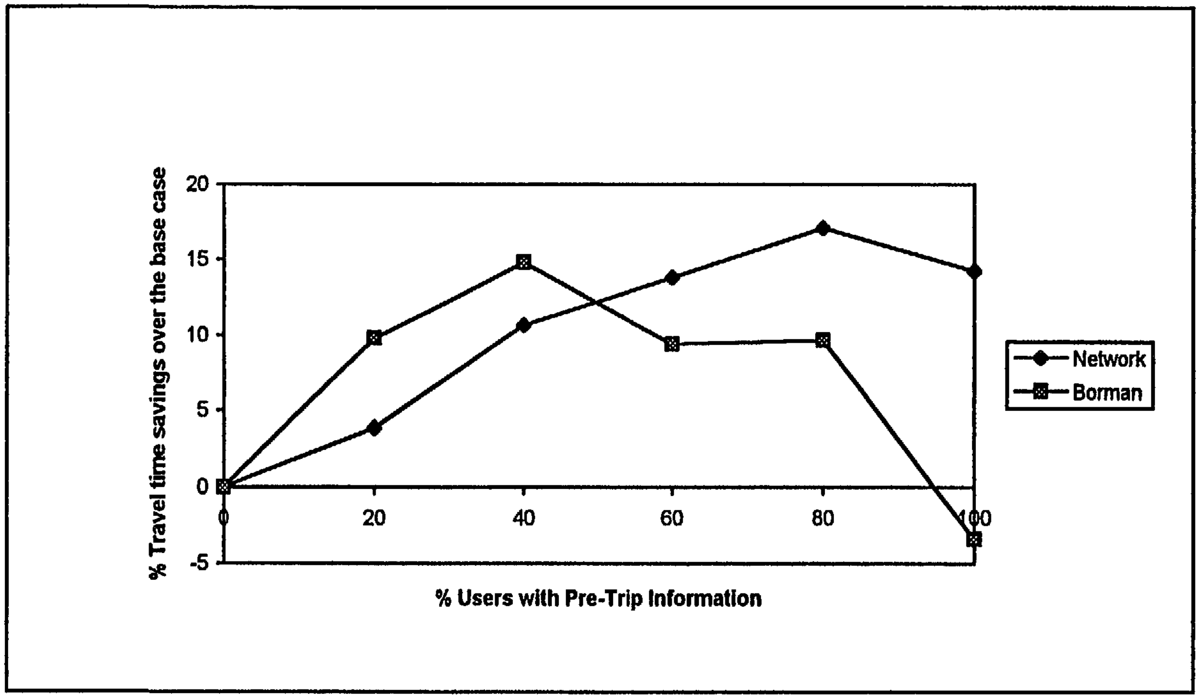

Figure 5.2. Scenario I (Normal Afternoon Peak Period): % Travel time savings over the base case for different levels of accessibility of Pre-trip information.

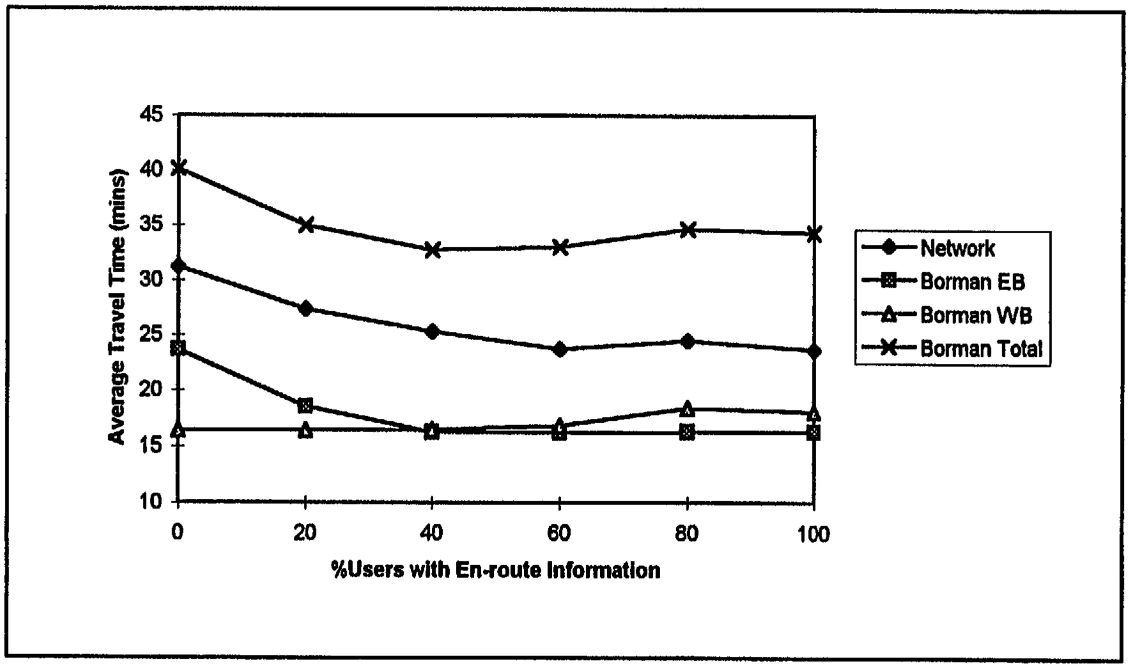

Figure 5.3. Scenario I (Normal Afternoon Peak Period): Variation of average travel time with the accessibility of En-route Information

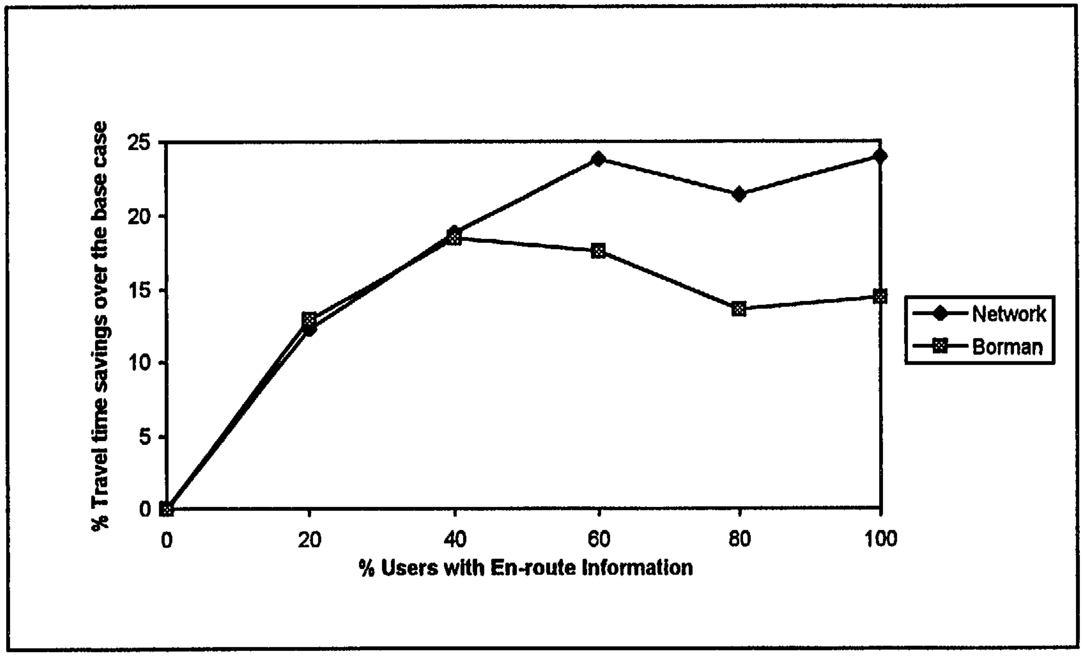

Figure 5.4. Scenario I (Normal Afternoon Peak Period): % Travel time savings over the base case for different levels of accessibility of En-route Information

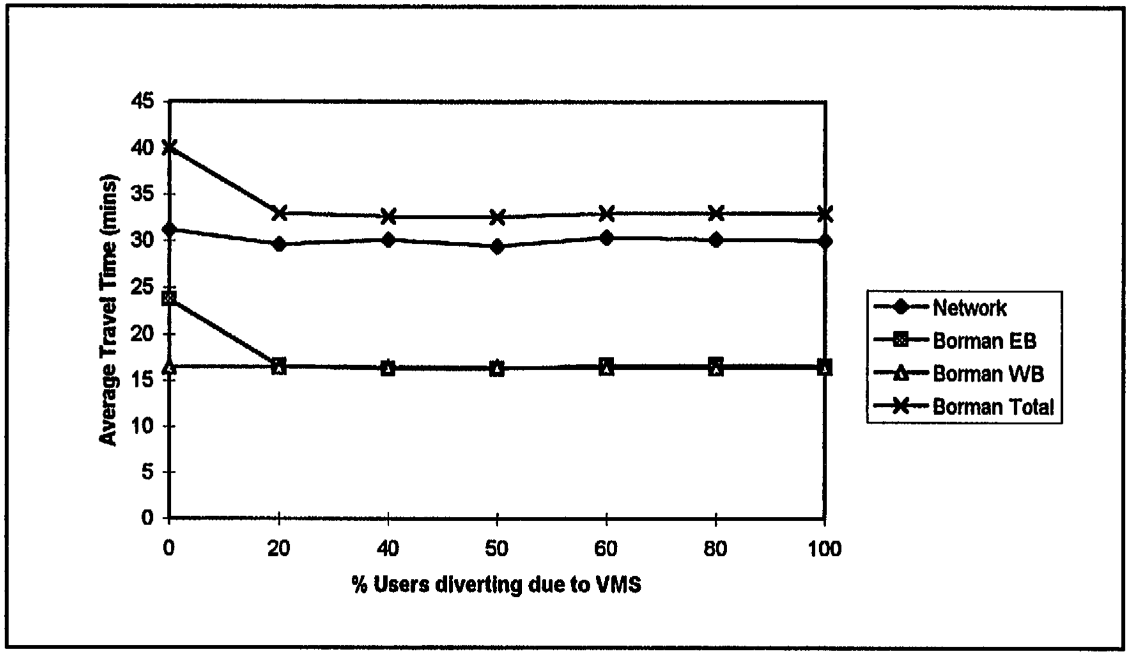

Figure 5.5. Scenario I (Normal Afternoon Peak Period) : Variation of average travel time with the % users willing to divert due to VMS.

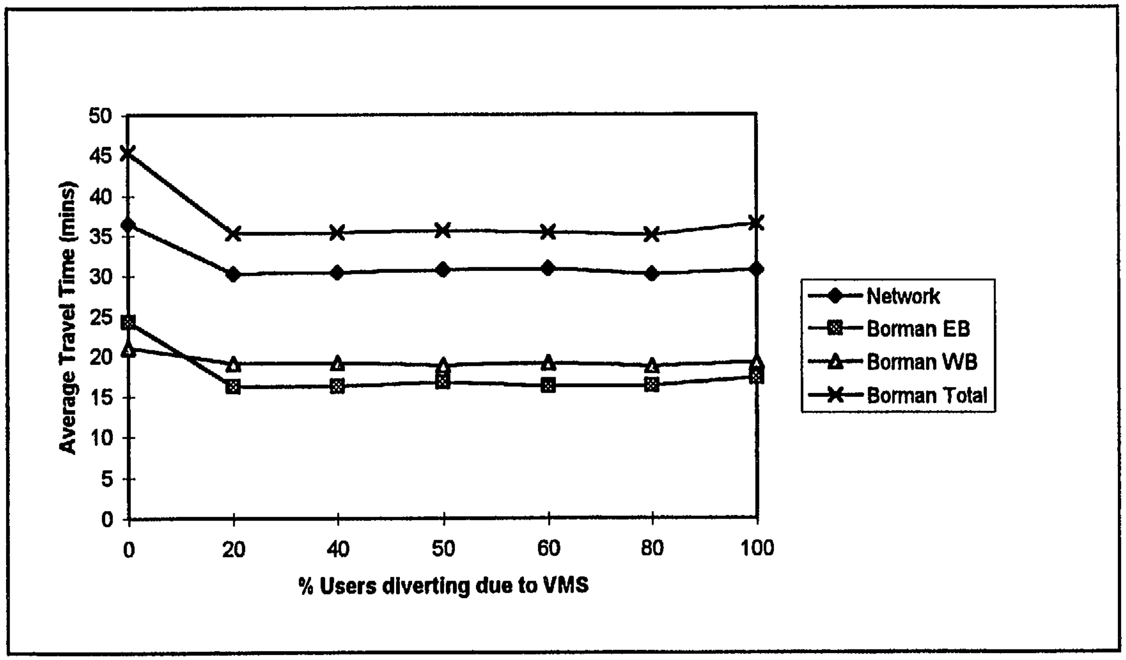

Figure 5.6. Scenario II (Lane Closure) : Variation of average travel time with the % users willing divert due to VMS.

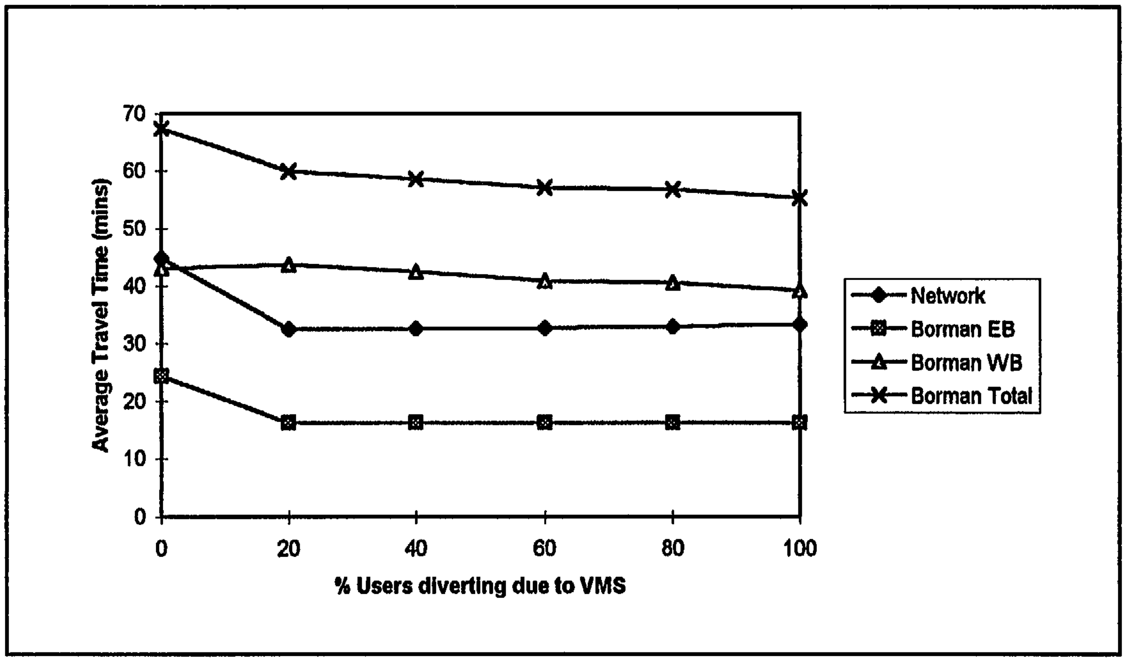

Figure 5.7. Scenario III (Link Closure) : Variation of average travel time with the % users willing to divert due to VMS.

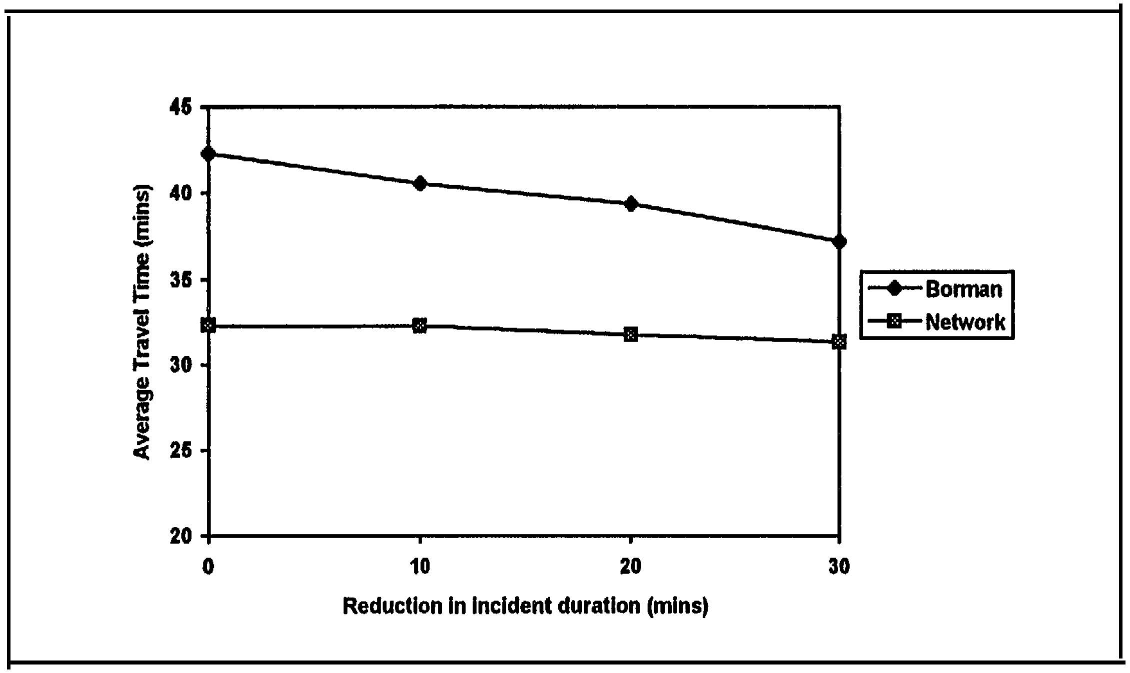

Figure 5.8. Scenario II (Lane Closure): (IMS) Variation of average travel time with reduction in incident duration

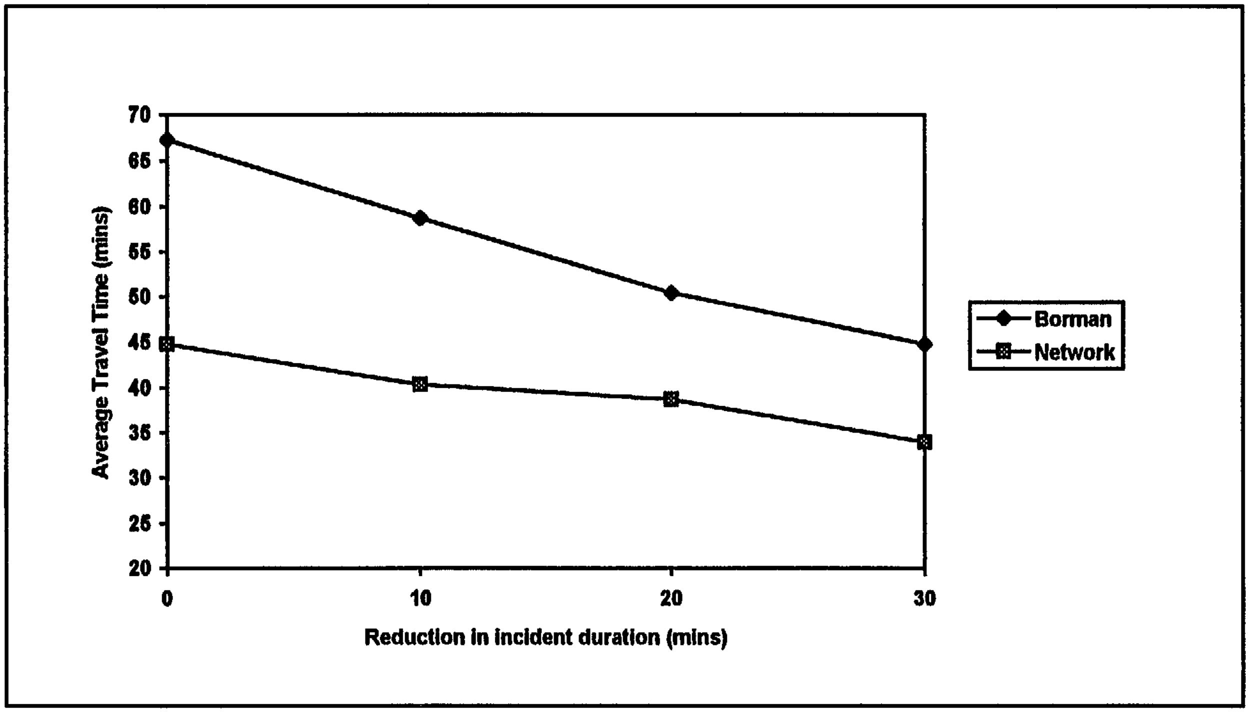

Figure 5.9. Scenario III (Link Closure): (IMS) Variation of average travel time with reduction in incident duration.

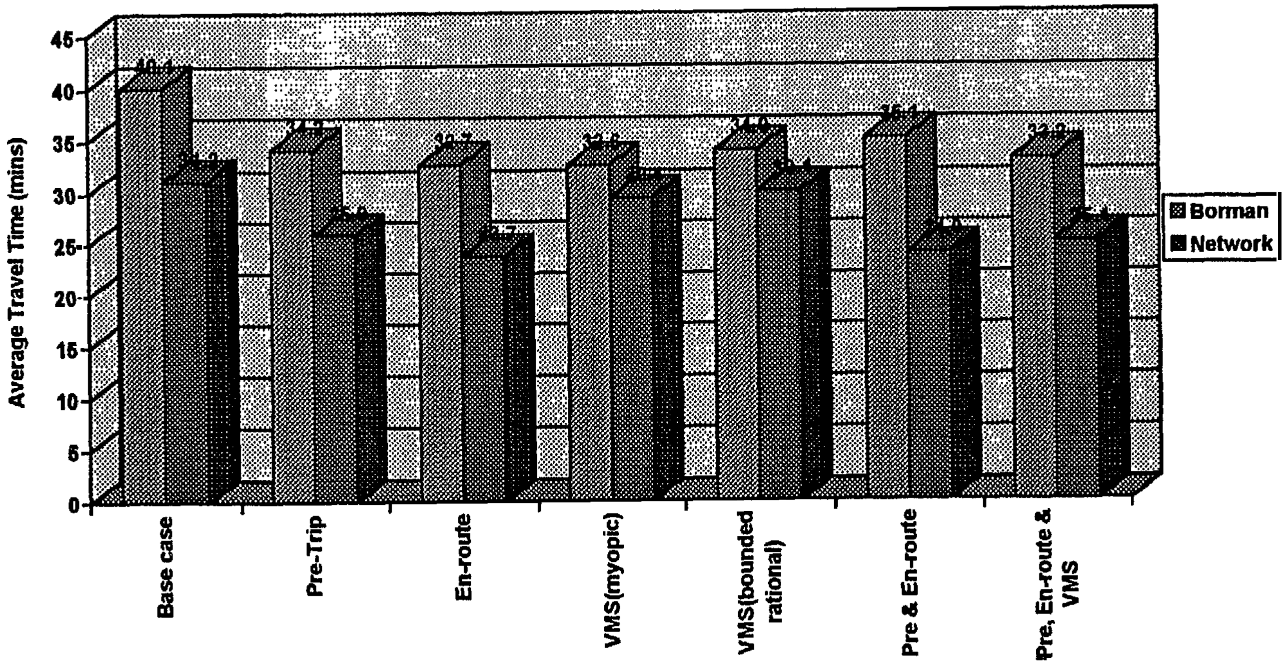

Figure 5.10. Scenario I (Normal Peak hour): Average travel time under various technologies

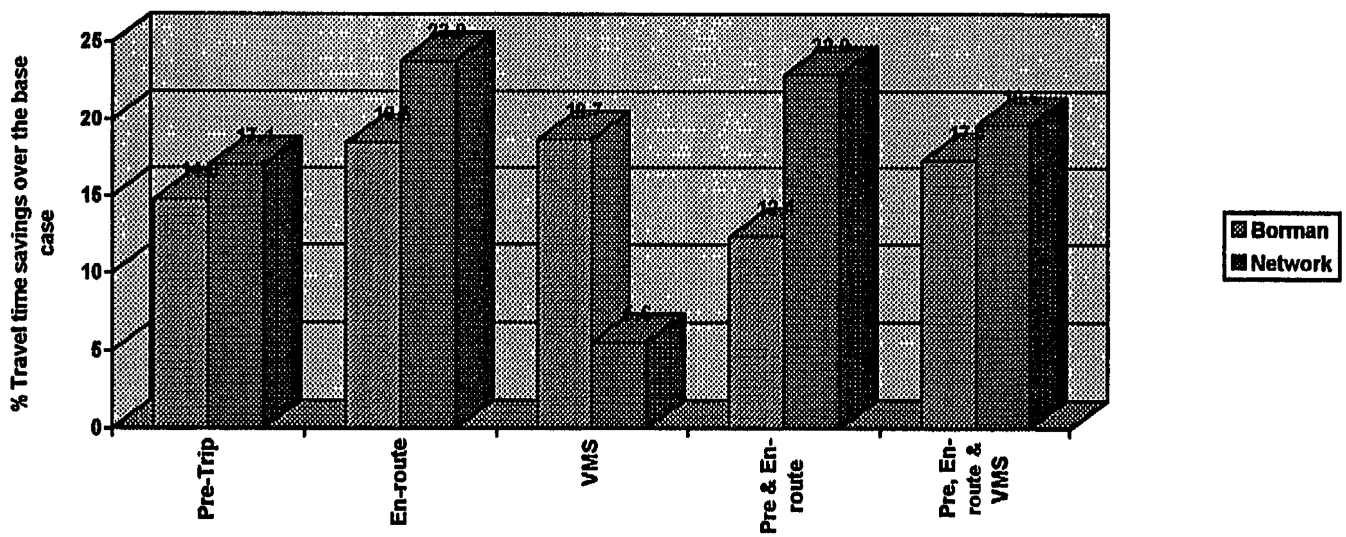

Figure 5.11. Scenario I (Normal Afternoon Peak Period): % Travel time savings over he base case with various technologies

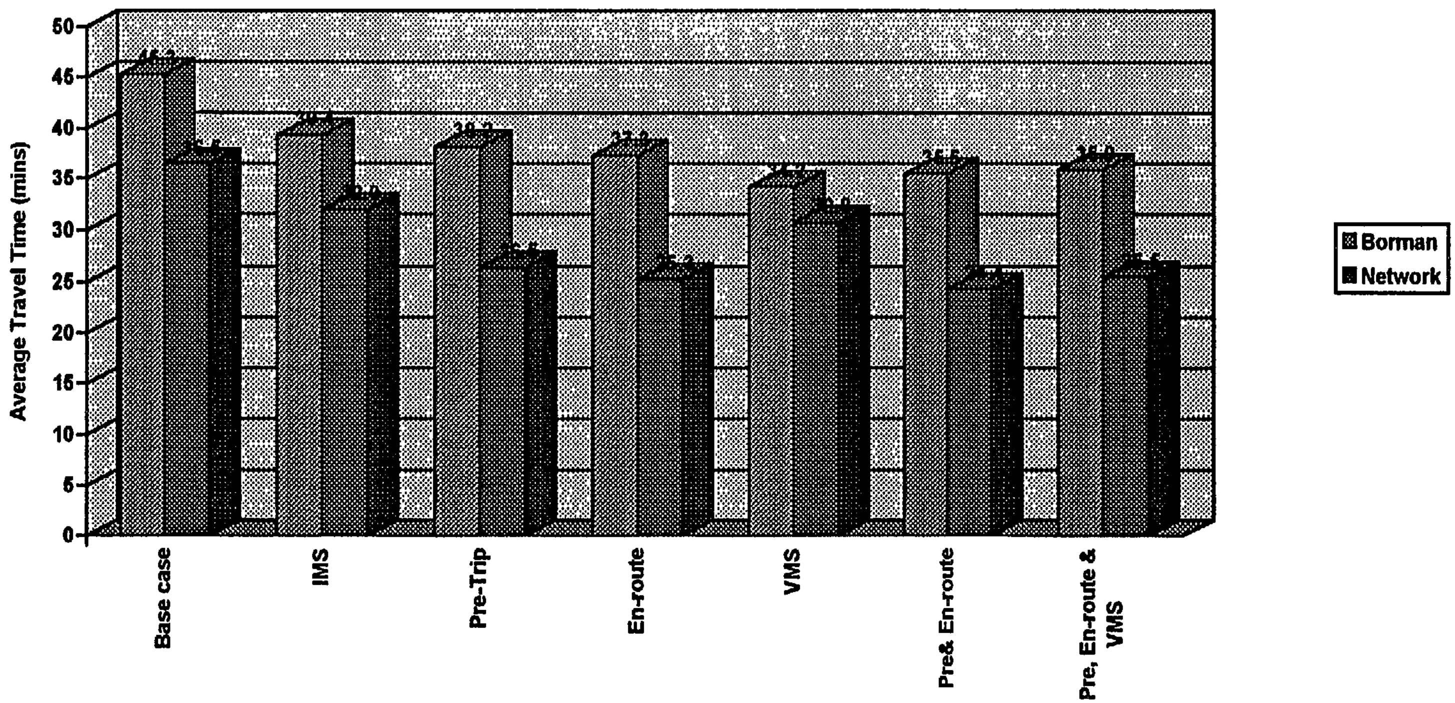

Figure 5.12. Scenario II (Lane Closure): Average travel time under various technologies

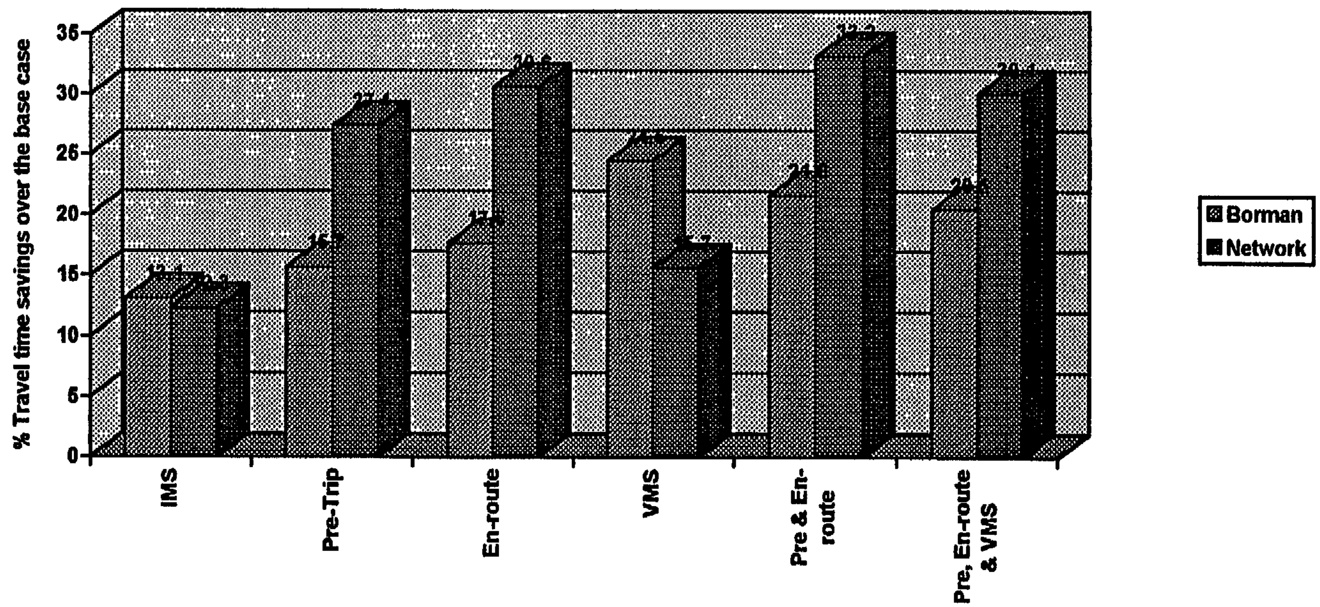

Figure 5.13. Scenario II (Lane Closure): % Travel time savings over the base case with various technologies

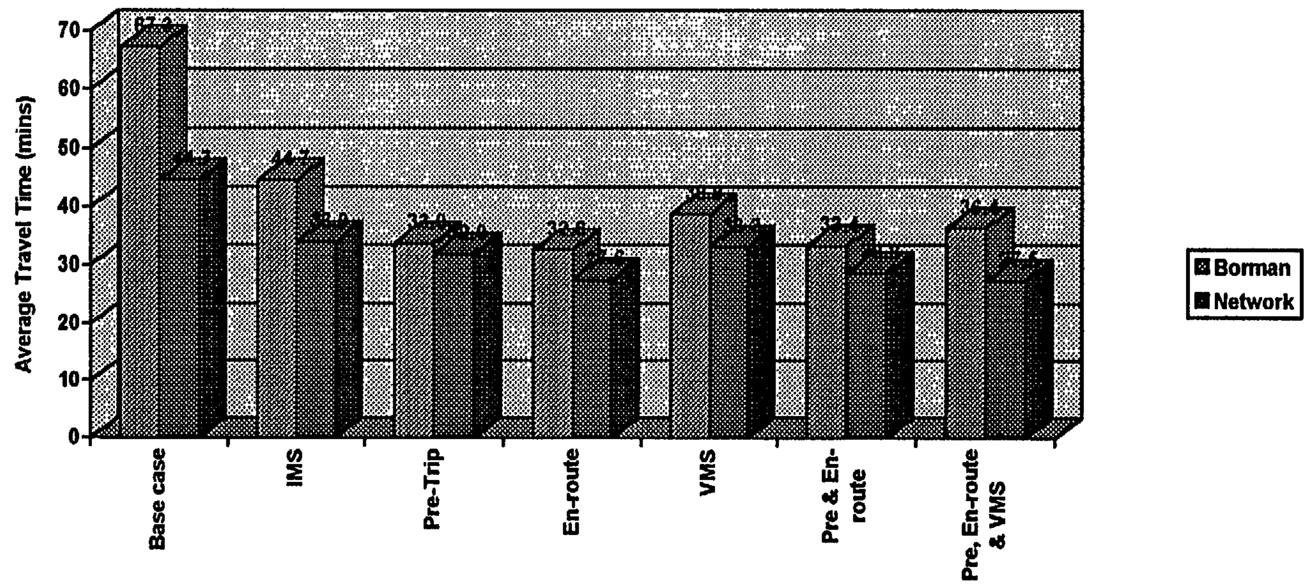

Figure 5.14. Scenario III (Link Closure): Average travel time under various technologies

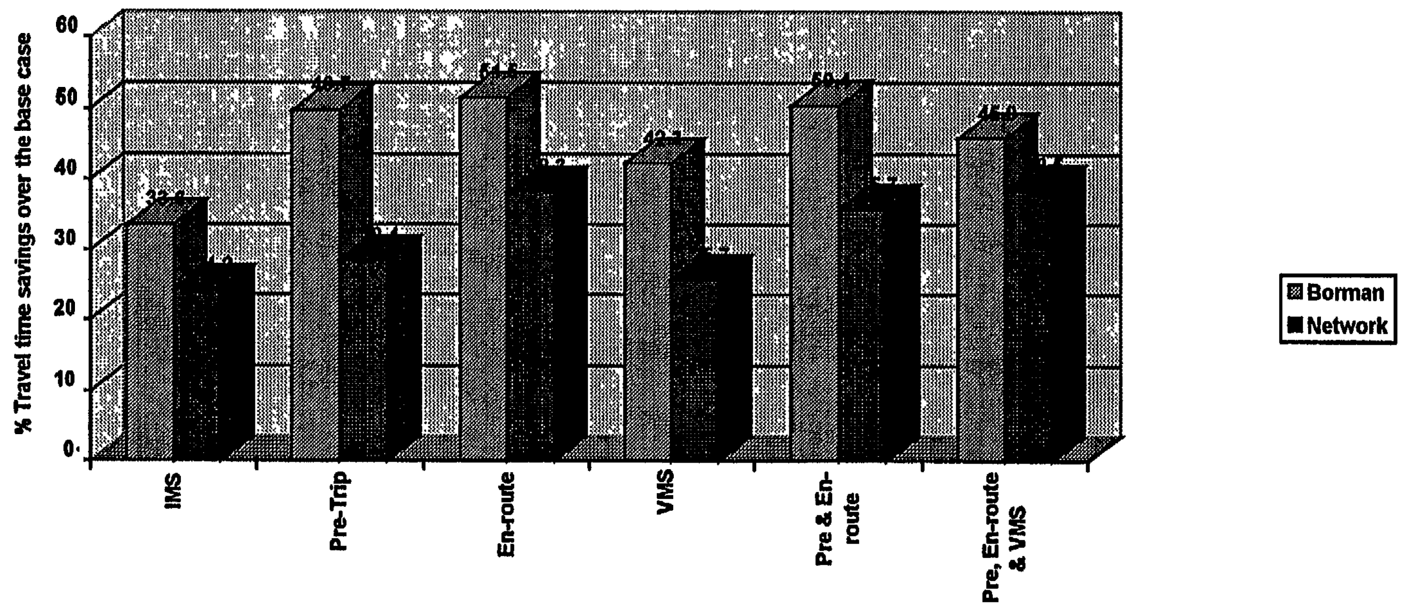

Figure 5.15. Scenario III (Link Closure): % Travel time sav over the base case with various technologies

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SECTION - II

EVALUATION OF ITS IMPACTS ON AIR QUALITY

1. INTRODUCTION

1.1 Background

The demand for surface transportation has been growing continually, and the ability to accommodate this demand has led to the menacing problem of congestion, which in effect, creates negative impacts on the surrounding air quality. The alleviation of this problem can be achieved by using the existing infrastructure in an efficient manner with the help of emerging technologies, which is exactly what the concept of Intelligent Transportation Systems (ITS) aims at accomplishing. The ITS working philosophy is based on the achievement of efficient traffic control and management in situations of recurrent and non-recurrent congestion, by the use of state-of-the-art sensing, processing and communication devices.

In 1993, two years after the passage of Intermodal Surface Transportation Efficiency Act (ISTEA), the Gary-Chicago-Milwaukee (G-C-M) transportation corridor became one of the four corridors selected by the U.S. Department of Transportation (USDOT) as national ITS priority corridors. The G-C-M corridor includes Borman Expressway, one of the most heavily traveled highways in the country, serving more than 140,000 vehicles each day. The Borman Expressway is a 16-mile section of I-80/94, located in Lake and Porter counties of Northwestern Indiana, connecting the Indiana and Illinois tollways. The main objective of the Borman ITS program is to improve mobility, safety, energy efficiency and environmental quality in the region. With its high traffic volume and high truck percentage, Northwestern Indiana comes under the severe category of ozone non-attainment areas. This research aims at developing a methodology for evaluating ITS impacts on air quality in the Borman Expressway corridor, by taking into account, the effects of congestion, queuing, idling and stop-delays in the estimation of mobile emissions.

1.2 Motivation

According to the Clean Air Act (CAA) of 1970 and 1977, any area where the emissions get higher than the EPA standards is defined as a non-attainment area. The 1990 Clean Air Act Amendments (CAAA) established additional mandatory requirements for non-attainment areas. They established a hierarchy of specific pollution control measures that are required to be implemented in non-attainment areas, depending on the severity of the pollution problem. Lake and Porter counties of Northwestern Indiana are part of a "severe" non-attainment area. This is the second most serious classification and applies to the largest metropolitan areas in the country, like Chicago, New York, and certain areas of Texas. The 1990 Amendment also requires the state to submit attainment plans containing measures to reduce emissions of air pollutants to bring the non-attainment areas into attainment by a specific deadline. For Lake and Porter counties, this deadline is 2007.

The program for ITS implementation in the environmentally sensitive Northwestern Indiana region, makes it necessary to study the air quality impacts with and without implementation scenarios. Since mobile emissions are very sensitive to the traffic flow characteristics, it is very important to conduct an air quality impact study to a very high level of sensitivity, capturing the effects of vehicle stops, acceleration and deceleration.

1.3 Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) apply emerging technologies in such fields as information processing, communications, control, and electronics to surface transportation needs. ITS encompasses a number of diverse program areas including Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), Advanced Vehicle Control Systems (AVCS), and Advanced Public Transportation Systems (APTS).

ATMS include systems designed to reduce recurrent and non-recurrent congestion levels by improving traffic signalization, incident detection, and corridor control. ATIS provide motorists with information on highway conditions and route availability to help them decide the best possible route before and during a trip. CVO increase the productivity of those vehicles engaged in the movement -of goods and services, by making use of technologies like weigh-in-motion, electronic vehicle identification, electronic data interchange, and wireless communications. AVCS include features that will help in avoiding collisions and potential conditions for collisions by providing appropriate information to drivers. APTS cover various concepts like ride-sharing information, traveler information service, traffic management systems, and transit and fleet management systems.

1.4 Borman Expressway ITS Program

In order to maintain a smooth flow of traffic on and around Borman Expressway, the Indiana Department of Transportation (INDOT) has implemented several components of ITS, as part of the G-C-M corridor ITS implementation scheme. This includes the Advanced Traffic Management Systems (ATMS), which uses expert systems software to monitor the flow of information from Hoosier Helpers (highway patrol vehicles), Indiana State Police, INDOT and Illinois DOT. This information is stored at the Traffic Operations Center (TOC), which makes use of the gathered information to keep motorists advised of the Borman's current status. Communication with motorists is accomplished in several ways, such as Variable Message Signs (VMS), and AM 530 radio channel.

The implementation of Incident Management Systems (IMS) on Borman Expressway is achieved by the Hoosier Helper program, using special highway patrol trucks, equipped with special communications equipment, a video camera, a video monitor, and emergency equipment for stalled vehicles. The Hoosier Helpers patrol Borman Expressway and a section of I-65, 24-hours a day, seven days a week, assisting the highway users in that region.

In addition to this, Close Circuit Televisions (CCTV) are currently used through cameras installed at Burr Street, Kennedy Avenue, and Cline Avenue interchanges on Borman Expressway. This enables the TOC to get video updates of traffic conditions at these interchanges, and increases the accuracy of information provided to the Borman users by the TOC.

1.5 Mobile Emissions

A mobile source of air pollution can be defined as one capable of moving from one place to another under its own power. According to this definition, a motorized vehicle is a mobile source, and the emissions from it are mobile emissions. The major pollutants emitted by motorized vehicles are hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x).

CO is a major transportation-related pollutant. It is a colorless, odorless gas whose principal source is incomplete combustion of organic fuels. It combines with the hemoglobin of the blood to produce carboxyhemoglobii and thereby, reduces the blood's abiity to carry oxygen. At sufficiently high concentrations, CO is fatal to humans. At the concentrations found in urban air, CO is not fatal, but it can aggravate cardiovascular and respiratory diseases.

Hydrocarbons (HC) are chemically defined as compounds of carbon and hydrogen. However, in air quality studies, the term "hydrocarbons" is often extended to include a variety of other volatile substances such as aldehydes and alcohols. At the concentration usually found in urban air, most hydrocarbons are not directly harmful. Their importance as air pollutants arises mainly from their role in atmospheric chemical reactions that produce nitrogen dioxide and ozone, both of which are harmful to or near atmospheric concentrations.

Nitrogen dioxide (NO_2) is a brownish gas with a pungent odor. It is responsible for the brownish color of he sky in many smoggy areas. The combination of all nitrogen oxides, consisting mainly of NO and NO_2, with small quantities of nitrogen tioxide (NO_s), diitrogen trioxide (N203), and nitrogen tetroxide (N2O4), is referred to as “nitrogen oxides” (NOx). NOx can react chemically in the air to form nitrous and nitric acid, nitrate salts, and certain organic compounds of nitrogen. Because many of these reaction products are acidic, NOx is an important contributor to acid rain. It also combines with HC to form ground-level ozone (O3).

1.6 Methodology

The methodology developed to evaluate ITS impacts on air quality is based on simulating peak-hour traffic on the Borman network, using INTEGRATION traffic simulation model. Several simulation runs were made for normal and incident conditions for do-nothing and ITS implementation scenarios, and emissions were estimated for all these scenarios. The ITS components studied in the simulation are Incident Management Systems (IMS), Variable Message Signs (VMS), and enroute information through other sources. The simulation model selected for this study has the provision for estimating HC, CO and NOx emissions, taking into account the speed profile of each and every vehicle in the network, the operating modes of all the vehicles, and the total number of vehicle stops due to congested conditions. The details of the simulation experiments and evaluation framework are given in Chapter 3.

1.7 Organization of Report

This report has mainly been divided into six chapters. This chapter is followed by the second chapter, which reviews the research efforts that have been made in the area of transportation-related air quality issues. It not only covers the work done to identify the factors affecting mobile emissions, but also discusses the impacts of ITS on air quality, and the current software that are in use to predict mobile emissions. This chapter is followed by the third chapter, where the study network and the methodology for evaluating ITS impacts on air quality is described, and details of the evaluation scenarios are given. The results of the various experiments are listed and discussed in the fourth chapter. ITS impacts on air quality can be assessed by the help of these results. This chapter is followed by the fifth chapter, which covers the sensitivity of mobile emissions to various traffuc characteristics such as average speed, number of stops, and truck percentage. The sixth and the last chapter lists final conclusions obtained from this research, and identifies the future research efforts that can be made in the area of ITS impacts on air quality.

2 . LITERATURE REVIEW

According to the National Transportation Statistics (1996) of the U.S. Department of Transportation, highway vehicles contributed 61.7% of carbon monoxide (CO), 31.8% of oxides of nitrogen (NO_x), and 26.1% of volatile organic compounds (VOC) to the national emissions in the year 1993. The magnitude of these emissions is heavily dependent on various trafic flow characteristics. These include the average speed of the flow, frequency and intensity of vehicle acceleration and deceleration, number of stops and the vehicle operating mode. It is a well-documented fact that high average speed, low frequency and intensity of acceleration and deceleration, low number of stops and stable vehicle operating mode, results in low mobile emissions. Hence, air quality around major transportation facilities can only be improved by ensuring a smooth and uninterrupted flow of vehicular traffic One way to achieve this goal is through the effective implementation of Intelligent Transportation Systems (ITS).

Over the past few years, extensive research has been done to evaluate the impacts of ITS on traffic mobility, and subsequently on mobile emissions. To the extent that ITS improve traffic operations and increase the efficiency of the transportation system, emission benefits are expected. However, it is still a matter of concern that improved level of service by ITS implementation, can result in higher trip attractions, which may lead to detrimental emissions effects. Addressing this issue, Ostria and Lawrence (1994) forecasted that both the long and short term air quality problems associated with congestion, poor vehicle maintenance, wasted travel, and too many vehicle trips may be alleviated by an array of ITS products, user services, and technologies that improve the level of service on highways, promote mode shifts that favor travel on higher occupancy vehicles, and supplement conventional emission control programs. Al-Deek et al. (1995) also came to a similar conclusion, indicating that ITS alone cannot compete with improved emission controls in reducing emissions. Emission controls and ITS together can achieve greater reductions of emissions than can be achieved by emission controls alone.

2.1 Factors Affecting Mobile Emissions

One important measure before evaluating ITS impacts on air quality, is the identification of the traffic flow parameters affecting the surrounding air quality, and their sensitivity to the magnitude of resulting emissions. It has long been confirmed after years of research and field experiments, that the major traffic related factors in mobile emissions are the average speed, vehicle acceleration and deceleration and vehicle operating mode. The major aim of the ITS program is to reduce travel time by reducing congestion. This leads to a smooth flow of traffic, resulting in higher average speed, lower number and intensity of accelerations and decelerations, and stable engine operating mode. Following is a summary of some of the research efforts made in analyzing the effects of these factors.

2.1.1 Vehicle Speed

Al-Deek et al. (1995) used EPA's emission software, MOBILES, to show the change in CO, NOx and VOC emissions, from a low speed of 5 mph to a higher speed of 65 mph, with 4 mph intervals. Their results show that at high speeds, CO and VOC emissions are minimum, but in case of NOx emissions are low at lower speeds. Their results show that CO emissions are maximum at 5 mph and minimum at 56 mph. A similar kind of trend is shown by VOC. But in case of NOx emissions curve shows a very diierent trend. NOx emissions are lower within a speed range of 21 to 31 mph, with a sharp increase above 47 mph. Cottrell (1994) used Highway Performance Monitoring System Analytical Process (HPMSAP) to estimate average travel speeds on a congested network. These values were used as input to MOBILES to come up with emission levels on networks under congested and free-flow conditions. For free-flow conditions, volume to capacity ratio from 0.0 to 0.1 was used, while for congested conditions, the ratio was kept from 0.975 to 1.0. The results indicated that CO emissions were 11 to 22 percent greater under congested conditions, depending on the facility type. In case of VOC, the emissions were 3 to 8 percent higher in congested conditions, while for NOx3 the emissions in congested conditions were 81 to 92 percent of the free-flow emissions. This study once again shows that CO and VOC emissions decrease with increase in average speed, while NOx emissions increase with an increase in the average speed.

In addition to the studies done to estimate emissions under congested conditions, there is a concern about the increase in emissions above an optimal speed, especially among the policy makers who are interested in analyzing the impacts of increasing the speed limits. Mullen et al. (1996) examined the impacts of speed limit changes on mobile emissions. They estimated that due to large increase in highway and arterial speed limits, CO, VOC and NO_x emissions may increase nationwide by 7%, 2% and 6% respectively. In the state of Texas, the NO_x emissions are estimated to have increased by 35% due to increased speed limits.

2.1.2 Vehicle Acceleration/Deceleration

Emissions have been shown to be highly dependent upon modal activity, particularly high accelerations that are associated with high load conditions. A long trip in steady flow conditions results in lower emissions as compared to emissions from a short trip with frequent accelerations and decelerations. As described by Barth et al. (1995), a single power acceleration can produce more carbon monoxide than is emitted in the balance of a typical short trip (<5 miles). In spite of this, forthcoming versions of emission estimating software are still expected to estimate emissions as a function of average speed, neglecting the effects of accelerations and decelerations. These models have been shown to underestimate emissions, in part because they do not explicitly account for much of the modal activity, i.e., the accelerations, decelerations, cruises and idles of individual vehicles in a traffic stream. The fundamental problem with the modeling methodology on which these models are based, lies in the fact that two vehicle trips with the same average speed may have different speed profiles that consist of very diierent modal activity. Hence, two similar trips may result in diierent emission profiles, however the model outputs cannot reflect these important differences. Hence the importance of acceleration/deceleration is underestimated in these models.

In a recent study done in San Francisco, Washington et al. (1997), used video-mounted helicopter to capture the modal activity of marked cars along different traffic streams. Collecting video footage from a helicopter allowed them to obtain the driving behavior of a large sample of individual vehicles. Their results indicated that the modal activity of a given facility is clearly composed of the modal activity from vehicles in each lane of the facility. The lane-by-lane modal activity distributions may be significantly different, and hence the contribution of each lane to the total emissions is likely to vary. Hence they concluded that an average measure of modal activity may not be adequate for representing the aggregate distribution of modal activity.

2.1.3 Vehicle Operating Mode

The operating modes of vehicles are broadly classified into two categories - transient and hot stabilized modes. The transient mode is further classified into cold start and hot start modes. The Environmental Protection Agency (EPA) has defined a cold start as any start that occurs 4 hours or later following the end of the preceding trip for noncatalyst-equipped vehicles, and 1 hour or later following the end of the preceding trip for catalyst-equipped vehicles. Hot starts are those that occur less than four hours after the end of the preceding trips for noncatalyst-equipped vehicles, and less than one hour after the end of the preceding trip for catalyst equipped vehicles. The time between the start and the end of the trip is called the hot-stabilized period. Emissions of carbon monoxide (CO) and volatile organic compounds (VOCs) are significantly high during the cold start engine operating mode because of low air to fuel ratios and poor performance of cold catalytic converters. In contrast to the HC and CO, emissions of oxides of nitrogen (NOx) tend to be low during the cold start mode.

The emission estimating model MOBILES, developed by the Environmental Protection Agency (EPA), has fixed values of the operating mode fractions. These values assume 20.6% of the total VMT in cold transient mode, 27.3% in hot transient mode, and the remaining 52.1% of the VMT in hot stabilized mode of operation. Extensive research has been done on testing the validity of these operating mode fractions, for diierent facility types, on diierent times of the day. Chatterjee et al. (1996), used MINUTP software to assign O-D trip tables to a study network, at diierent time periods. Using the definition of hot starts, cold starts and hot-stabilized operating modes, they found out the percentage of VMT. in each operating mode for the test network, according to the time distribution of the trips. They came up with diierent percentages of the total VMT in cold transient, hot transient, and hot stabilized mode, for diierent time periods of the day. These values reflect a huge deviation from the values set by EPA for MOBILES. For example, for a 24-hour period, the percentage of the total VMT obtained from their study is 25.82 for cold transient, 17.20 for hot transient, and 56.98 for hot stabilized mode. In addition to predicting the operating mode fractions on time-of-day basis, they also estimated the operating mode fractions classified on the basis of the roadway facility type. These include operating mode fractions for VMT on freeways, expressways, major arterials, minor arterials, collector roads, freeway ramps, locals roads and all roads.

In another such effort, Venigalla et al. (1994a), came up with a methodology for estimating operating mode fractions for urban areas, based on urban population. The urban area categories used, were according to the Nationwide Personal Travel Survey (NPTS) classification. The four categories of the urban area population range studied were 50,000 to 199,999, 200,000 to 499,999, 500,000 to 999,999, and over 1000,000. Their study indicated that in most cases, the average VMT fraction of cold starts was more than 30 percent instead of the 20.6 percent as derived from the FTP drive cycle for use in MOBILES.

2.2 Impacts of ITS on Air Quality

In a study done at the University of Central Florida, Al-Deek et al. (1995) evaluated the impacts of rerouting tragic guided with Advanced Traveler Information Systems (ATIS) on air quality. They used MOBILES to estimate total emissions of CO, VOC and NOx on two routes with and without ATIS. These evaluations were made for three time periods: 1993-1998, 1998-2003, and beyond 2003. They estimated corridor-level emissions for scenarios with 0 to 100 percent of users provided with information. Their findings indicate that a system-wide reduction of CO and VOC can be achieved through the implementation of ATIS, and higher reductions in these emissions can be achieved with higher ATIS market-penetration levels. But the trend for NOx emissions was not found to be the same. Lower NOx emissions were only found for low market-penetration level, while for high market-penetration, ATIS showed a negative impact on NOx emissions.

In addition to this, numerous studies have been done to come up with a framework for ITS impact evaluation. In a research effort, Underwood and Gehring (1993) identified field experiments, surveys, subject debriefing, cost analysis, and extrapolated impact assessment as the various stages of ITS impact evaluation framework. In a similar effort, Spasovic et al. (1995), proposed a framework for ITS impact evaluation, by evaluating the benefits from the introduction of information services in highway networks, and quantifying the gains by having perfect or partial information to users. Brand (1993) suggested to look into this matter by clearly defining the requirements on the demand and supply side. He identified transportation systems operations, ITS costs, and investment costs as the key input factors, and mobiity, economic development, safety, environment and energy benefits as the immediate and long term benefits. Skabardonis (1997) used the combination of TRAF_NETSIM, INTRAS, and MINUTP on a Bay Area network, to come up with a modeling framework for estimating emissions in large urban areas.

Other research efforts made to aid the evaluation of ITS impacts on air quality are by Walker (1990) in studying the impact of pre-aggregation of network travel data on accuracy of mobile emissions estimation, Helali and Hutchinson (1993) in studying the effects of accuracy of speed estimates in estimating emissions, and Wang and Santini (1994) in establishing a monetary value for air pollutants through mobile sources. In addition to this, DeCorla-Souza et al. (1993) suggested trip-based approach to estimate emissions with EPA’s MOBILE model, Fleet and DeCorla-Souza (1991) discussed the importance of VMT for air quality purposes, Guensler (1993) identified the data needs for evolving motor vehicle emission modeling approaches, Chatterjee et al. (1991) worked on the estimation of travel related inputs to air quality models, Venigalla et al. (1994b) developed alternative operating mode fractions to FTP mode mix, and LeBlanc et al. (1994) studied the impacts of driving pattern variability on mobile emissions The impact of travel demand predictions on the accuracy of mobile emission estimates is another area in which substantial amount of research has been done. Stopher and Fu (1996) studied the travel demand analysis impacts on estimation of mobile emissions. In another such effort, Stopher (1993) identified the deficiencies of travel-forecasting methods relative to mobile emissions. Walker (1990), studied the impact of pre-aggregation of travel data on accuracy of mobile emissions estimation.

2.3 Mobile Emissions Software

2.3.1 MOBILE5

MOBILE5 is an emission estimation software developed by the United States Environmental Protection Agency (USEPA). Its latest version, MOBILES, was released on March 26, 1993. The MOBILE5 User's Guide (U.S. EPA, 1994), describes it as an integrated set of FORTRAN routines for use in analysis of the air pollution impact of gasoline-fueled and diesel powered highway mobile sources. The program provides the user with a flexible analytical tool that can be applied to a wide variety of air quality modeling and planning functions. It estimates hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxides (NOx) emission factors for gasoline-fueled and diesel highway motor vehicles. It calculates emission factors for eight individual vehicle types in two regions (low and high altitude), based on various factors such as average travel speed, operating modes, ambient temperatures, fuel volatility, and mileage accrual rates. It can estimate emission factors for any calendar year between 1960 and 2020, and for any of the eight vehicle types as specified in the user manual. These vehicle types are light-duty gasoline vehicles (LDGVs), light-duty gasoline trucks (LDGTs), heavy-duty gasoline vehicles (HDGVs), light-duty diesel vehicles (LDDVs), light-duty diesel trucks (LDDTs), heavy-duty diesel vehicles (HDDVs) and motor cycles (MCs). The LDGTs are further classified into LDGTl s and LDGT2s based on their gross and loaded weights.

2.3.2 INTEGRATION

INTEGRATION is a traffic simulation model developed in 1985 by Van Aerde at Queens University, Canada. As described in the User's Guide Volume I (Van Aerde, 1995), INTEGRATION is a fully microscopic simulation model, as it tracks movements of individual vehicles up to one deci-second. It estimates HC, CO and NOx emissions on second-by-second basis. These estimates are sensitive to vehicle speed profile, traffic volume and the vehicle operating mode. In other words, it captures the effects of vehicle acceleration, deceleration, stops and idling in predicting mobile emissions. INTEGRATION also provides the options for simulating various components of ITS, such as IMS, ATIS and VMS, and also predicts the fuel consumption based on the speed changes in the network. The types of analysis that can be performed by INTEGRATION extend far beyond the capabilities of EPA's MOBILE5 model, which considers a single fixed speed profile for any given average speed, and considers primarily the number of vehicle miles traveled as the main predictor variable.

2.4 Discussion

It can be gathered from the literature review that the sensitivity of mobile emissions depends on certain traffic flow characteristics, and effective implementation of ITS can result in significant changes in these characteristics. Although some studies have shown ATIS having positive effects on CO and HC emissions and negative effects on NO, emissions, the need for simulating actual traffic conditions on a selected network is necessary to come up with concrete conclusions. Furthermore, it can be seen that none of the studies performed on air quality impacts of ITS has captured the effect of smoothness of traffic flow by taking into account the drastic changes in emissions caused by vehicle accelerations, decelerations and stops.

3. EVALUATION METHODOLOGY

To evaluate ITS impacts on air quality, it is necessary to simulate the actual traffic conditions on the Borman network, using the same network specifications, link characteristics, signal timing plans and O-D demand. In addition to this, the experiments should include various scenarios under normal and incident conditions. To achieve such flexibiity in modeling, INTEGRATION simulation software was used. INTEGRATION not only satisfies the above mentioned conditions, but also provides the options for simulating various applications of ITS, such as IMS, ATIS and VMS. In addition to this, it has the ability to predict estimates of HC, CO and NOx emissions based on the speed profile of each and every vehicle present in the network. In other words, it captures the effects of vehicle acceleration, deceleration, stops and idling in predicting mobile emissions. The sensitivity of mobile emissions to these traffic flow characteristics is very high, and the change in these characteristics after ITS implementation can result in drastic changes in emission levels.

The methodology adopted is based on half-an-hour simulation of different scenarios, evaluating the performance of three diierent ITS technologies under normal and incident conditions, as shown in Figure 3.1. This chapter describes the coding of the network O-D matrix , and the details of all the scenarios used as a framework to evaluate ITS impacts on air quality.

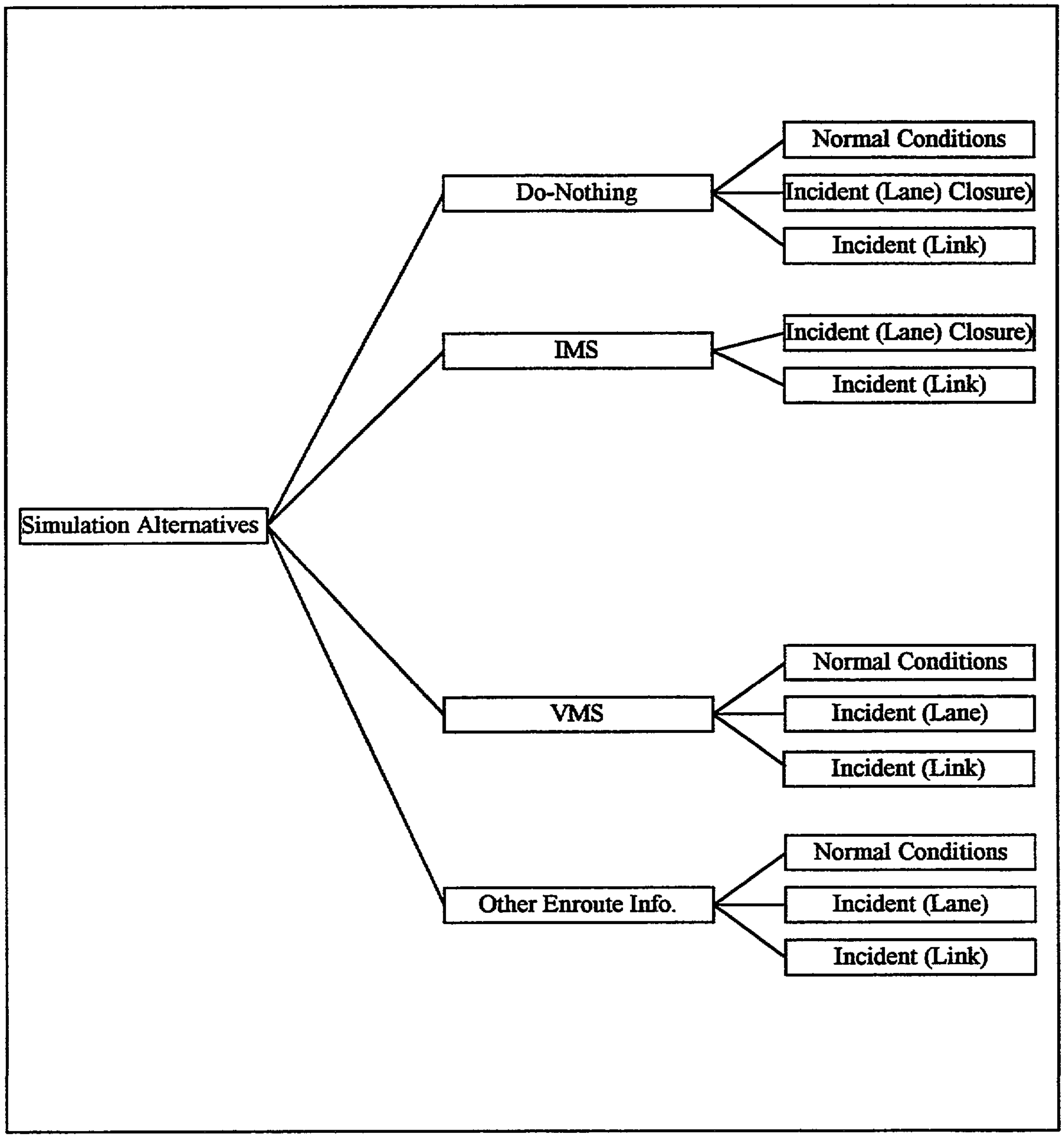

Figure 3.1 : INTEGRATION Simulation Scenarios for Borman Evaluation Network

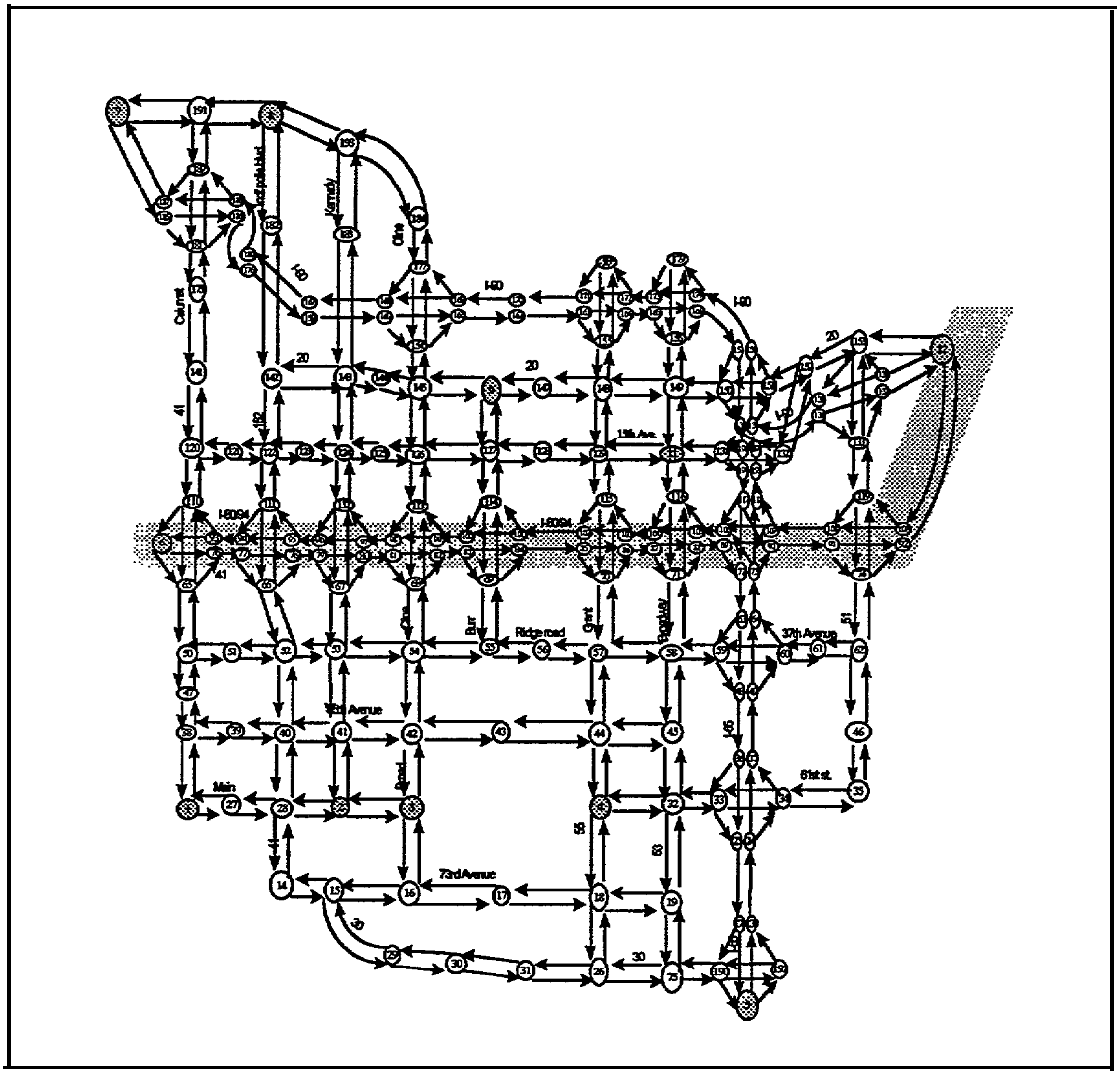

Figure 3.2 : Borman Expressway Evaluation Network

3.1 Study Network

The study network, located in Northwestern Indiana, consists of three major interstates in one of the most congested sections of the Gary-Chicago-Milwaukee (GCM) corridor (see Figure 3.2). In addition to Borman Expressway, a 16-mile section of it consists of portions of I-90, I-65 and other major arterials. The total length of the network is 765 lane-miles. It consists of 190 nodes and 439 links, controlled by a total of 75 signals. The number of interchanges in the network is 19. There are 12 O-D zones in the network, shown by the shaded nodes in Figure 3.2.

3.2 O-D Matrix

The O-D matrix used for this study was obtained from an O-D survey done by the Northwestern Indiana Regional Planning Commission (NIRPC) in the year 1990. This O-D matrix was updated to 1996 values using the factors provided by the Indiana Department of Transportation (INDOT). This matrix was based on 844 zones in Northwestern Indiana and Northeastern Illinois. These values for 844 zones were aggregated to a total of 12 node-based O-D zones for the study area. The shaded nodes in Figure 3.2 are the O-D nodes.

It should be noted that Borman Expressway comes under one of the heaviest traveled highways in the country, serving more than 140,000 vehicles each day. A substantial percentage of the traffic moving on Borman is truck traffic, using it as an important link from east coast to west coast and vice versa. Another important point is the location of a large city like Chicago near it. The traffic moving to and from Chicago, combined with the through truck traffic causes huge back-ups, especially under peak-hour incident conditions. This results in longer delays, stop-and -go traffic and higher emissions.

3.3 Modeling

The coding of the simulation model was done by keeping the perfect replication of the actual network conditions in perspective. A total of eleven simulations were made, and the emissions levels with and without ITS scenarios were obtained for the normal and incident conditions. Each simulation was run for a period of 30 minutes using the peak hour O-D. The description of each scenario is given in the following sections.

3.3.1 Do-Nothing Scenario

The do-nothing scenario was simulated to estimate the emissions under current traffic conditions. This also served as the base case for comparing the results after ITS implementation. To replicate the actual traffic movement in the network, the traffic from node 1 to 6 and 6 to 1 was forced to travel on I-65 and I-80/94. This was done by defining this demand as a different user class, prohibited to take exit from I-65 and I-80/94. This procedure was repeated for the traffic moving from node 1 to 7 and 7 to 1, and from 6 to 12 and 12 to 6. Furthermore, the percentage of trucks was fixed at 30 percent for the traffic moving to and from these nodes. This scenario was considered for three different cases to obtain the results for normal and incident conditions:

a) Normal traffic conditions with no incidents on the network.

b) An incident blocking a lane of a west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

c) An incident blocking whole of the west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

3.3.2 Incident Management Systems (IMS)

This scenario covers the impacts of the services provided by the Incident Management Systems on Borman Expressway. Currently, this service is provided by Hoosier Helpers, who patrol Borman Expressway and the northern section of I-65 to provide user help in case of an incident or any other emergency. It is assumed that the total incident clearance time is reduced by 50% due to the Hoosier Helper program, and this is modeled by reducing the incident duration by 50% in the conditions described in the previous section. Hence the two conditions obtained are:

a) An incident blocking a lane of a west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 10.0 minutes.

b) An incident blocking whole of the west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 10.0 minutes.

3.3.3 Variable Message Signs (VMS)

The VMS is a very useful component of ITS, especially under incident conditions. It gives diversion messages to the downstream traffic before it reaches the congested link. INTEGRATION offers the option of providing VMS facilities on various locations on the network to divert traffic from the congested link. The percentage of vehicles diverting on

VMS information can be assumed. These users retain the VMS information for three minutes after crossing the sign. The three cases modeled for VMS applications are:

a) VMS information provided to 20 percent of the users under normal traffic conditions with no incidents on the network.

b) VMS information provided to 20 percent of the users with an incident blocking a lane of a west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

c) VMS information provided to 20 percent of the users with an incident blocking whole of the west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

VMS was modeled on a total of 10 locations on the network; 8 on Borman Expressway and 2 on I-65. The exact locations of the VMS can be seen in Figure 3.3.

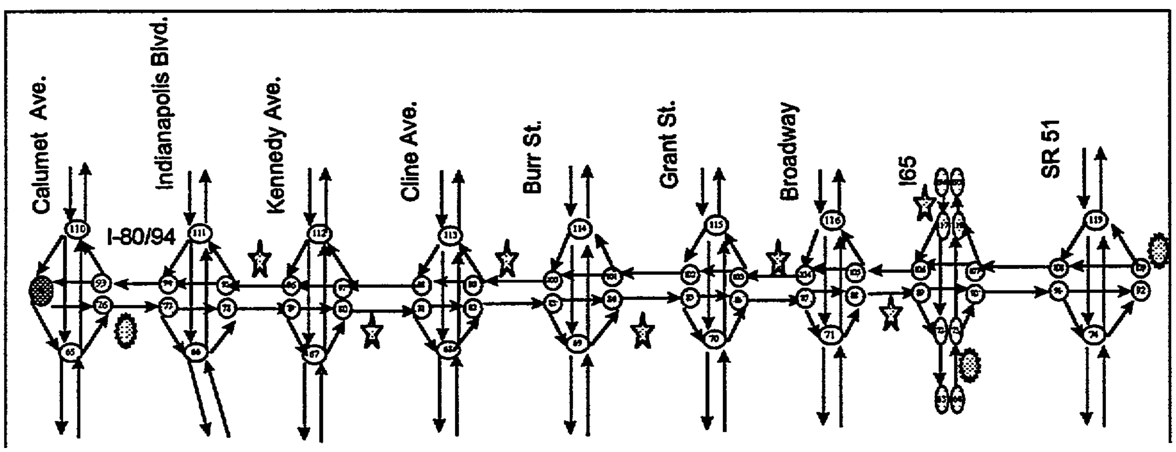

Figure 3.3 : VMS Locations on Borman Expressway and I-65

3.3 .4 Other Enroute Information

This section covers all other forms of enroute information other than VMS. These other forms of information can be Highway Advisory Radio (HAR), In Vehicle Navigation System (IVNS) or cellular phone traffic update. INTEGRATION models this component of ITS by providing updates on network traffic conditions to a specified percentage of users at specified time intervals. The traffic information update interval set for this study is 180 seconds. The three conditions covering this component of ITS are:

a) Enroute information provided to 60 percent of the users under normal traffic conditions with no incidents on the network.

b) Enroute information provided to 60 percent of the users with an incident blocking a lane of a west-bound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

c) Enroute information provided to 60 percent of the users with an incident blocking whole of the westbound link on Borman Expressway between Kennedy Avenue and Indianapolis Boulevard for a period of 20 minutes.

3.4 Emission Model

INTEGRATION simulation model was used for the impact evaluation. It was preferred over MOBILES because of the adopted methodology, which requires simulation of all the scenarios described above, including the simulation of ITS components such as IMS, VMS and other sources of enroute information. Another overriding factor for using INTEGRATION is that the network is tested for recurrent and non-recurrent congestion, resulting in greater number of stops, accelerations, and decelerations, which can be reduced by ITS implementation. Due to the high sensitivity of these factors to mobile emissions, and for capturing the effects of benefits in terms of emissions reduction from ITS implementation, INTEGRATION software was used, as it incorporates the effects of vehicle stops, accelerations, and decelerations. On the other hand, MOBILES estimates emissions based on the average speed of tragic and the total VMT, neglecting the effects of vehicles stops, accelerations, and decelerations. That is why, in INTEGRATION User's Manual, this effect is described by stressing the fact that for low volume conditions, MOBILES results were found to be close to the results obtained from INTEGRATION, but for high volumes, emission estimates from INTEGRATION were found to be much higher, reflecting the ability of INTEGRATION to capture the effects of congestion in mobile emissions.

3.5 Discussion

It can be seen from the above given description that the experimental setup for this evaluation framework covers all the possible components of ITS that have been or will be implemented on Borman Expressway, and it provides a solid ground for comparison of mobile emissions under diierent scenarios. The simulations were run for 30-minute simulation time for each scenario, and took 90 to 120 minutes of real time to get the results. The network-level results of emissions were converted to hourly emissions and are shown in tabular and graphical forms in the following sections.

4. AIR QUALITY ASSESSMENT

This section discusses the results obtained from the experiments of the ITS impact evaluation framework. The emissions are shown in grams per hour, and the fuel consumption values are shown in liters. The results for the entire network, obtained from the experiments using the INTEGRATION simulation model are shown in Table 4.1 and 4.2. The results in the form of percentage reduction in emissions over the base case, and the percentage reduction in fuel consumption over the base case, are shown in Tables 4.3 and 4.4, respectively.

The CO, HC and NOx emissions are also presented graphically, showing the percentage reduction with respect to the do-nothing scenario for all the three ITS components, for normal, lane-closure, and link-closure conditions. These results are shown for the entire network, and for Borman alone. It should be noted that only two components of ITS are shown in figures for normal conditions, because for normal (no incident) conditions, the simulation of IMS is not required. Furthermore, the reduction in the percentage of network-level fuel consumption with respect to the do-nothing case, is also shown graphically in Figure 4.10, covering the normal, lane-closure, and link-closure scenarios. It should be made clear that the network-level results indicate the results for Borman plus the results for the surrounding network. These results are analyzed and briefly discussed in the following ***sections*** of this chapter.

Table 4.1 : HC, CO and NOx Emissions on Borman Network

scenario	Condition	HC Emissions (grams/hr)	CO Emissions (grams/hr)	NOx Emissions (grams/hr)
Do-Nothing	Normal	4958210	17960049	2004893
	Lane-Closure	6525861	24200526	2606526
	Link;-Closure	8997493	34799617	2893642
IMS	Normal	N/A	N/A	N/A
	Lane-Closure	497923 1	18465001	2262465
	Link-Closure	6523 182	24916526	2430659
VMS	Normal	4150021	15086441	1822448
	Lane-Closure	503 1439	18561803	2207728
	Link-Closure	6595162	25542919	2283083
Other Enroute Info.	Normal	3986401	14727239	1846506
	Lane-Closure	5024913	18707006	2220760
	Link-Closure	6667142	25751717	2291764

Table 4.2 : Fuel Consumption on Borman Network

Scenario	Condition	Fuel Consumption (liters)
Do-Nothing	Normal	236869
	Lane-Closure	319163
	Link-Closure	458920
IMS	Normal	N/A
	Lane-Closure	244159
	Link-Closure	326751
VMS	Normal	196127
	Lane-Closure	245755
	Link-Closure	338224
Other Enroute Info.	Normal	190442
	Lane-Closure	251181
	Link-Closure	335470

Table 4.3 : Percentage Reduction in Network-Level Emissions for Normal Conditions

Scenario	HC Emissions Reduction (%)	CO Emissions Reduction (%)	NOx Emissions Reduction (%)
IMS	N/A	N/A	N/A
VMS	16.3	16.0	9.1
Other Enroute Info.	19.6	18.0	7.9

Table 4.4 : Percentage Reduction in Network-Level Emissions for Incident Conditions (Lane-Closure)

Scenario	HC Emissions Reduction (%)	CO Emissions Reduction (%)	NOx Emissions Reduction (%)
IMS	23.7	23.7	13.2
VMS	22.9	23.3	15.3
Other Enroute Info.	23.0	22.7	14.8

Table 4.5 : Percentage Reduction in Network-Level Emissions for Incident Conditions (Link-Closure)

Scenario	HC Emissions Reduction (%)	CO Emissions Reduction (%)	NOx Emissions Reduction (%)
IMS	27.5	28.4	16.0
VMS	26.7	26.6	21.1
Other Enroute Info.	25.9	26.0	20.8

Table 4.6 : Percentage Reduction in Fuel Consumption for Borman Network

Scenario	Normal Conditions	Incident Conditions (Lane-Closure)	Incident Conditions (Link-Closure)
IMS	N/A	23.5	28.8
VMS	17.2	23.0	26.3
Other Enroute Info.	19.6	21.3	26.9

4.1 HC Emissions

It can be seen Ii-om Figure 4.1 that for normal conditions, higher reduction in network-level HC Emissions is achieved through providing enroute information to 60 percent of the users, as compared to that of VMS information. A similar kind of trend can be seen for HC emissions on Borman only, but it can be seen that the magnitude of reduction of HC emissions is higher on Borman as compared to that of the network. This is especially because the traffic on Borman uses the information provided by VMS to divert in case of congestion, leaving a relatively smoother flow of traffic on the expressway.

Figure 4.2 shows that in case of an incident blocking a lane on one of the links on Box-man Expressway, the trend in emission reduction is same as that for the normal case. One noticeable point in this case is that IMS result in a higher reduction of HC emissions, as compared to enroute information and VMS. The comparison of Figure 4.1 and 4.2 shows that the magnitude of emissions reduction is higher incase of lane closure, as compared to the magnitude of emissions reduction under normal conditions.

The simulation results for the case of an incident blocking a link on Borman Expressway again show that IMS prove to be more effective in emission reduction under incident conditions, as compared to the other two components of ITS (Figure 4.3). Furthermore, it can be seen that the magnitude of emission reduction in this case is higher than that of the previous two cases.

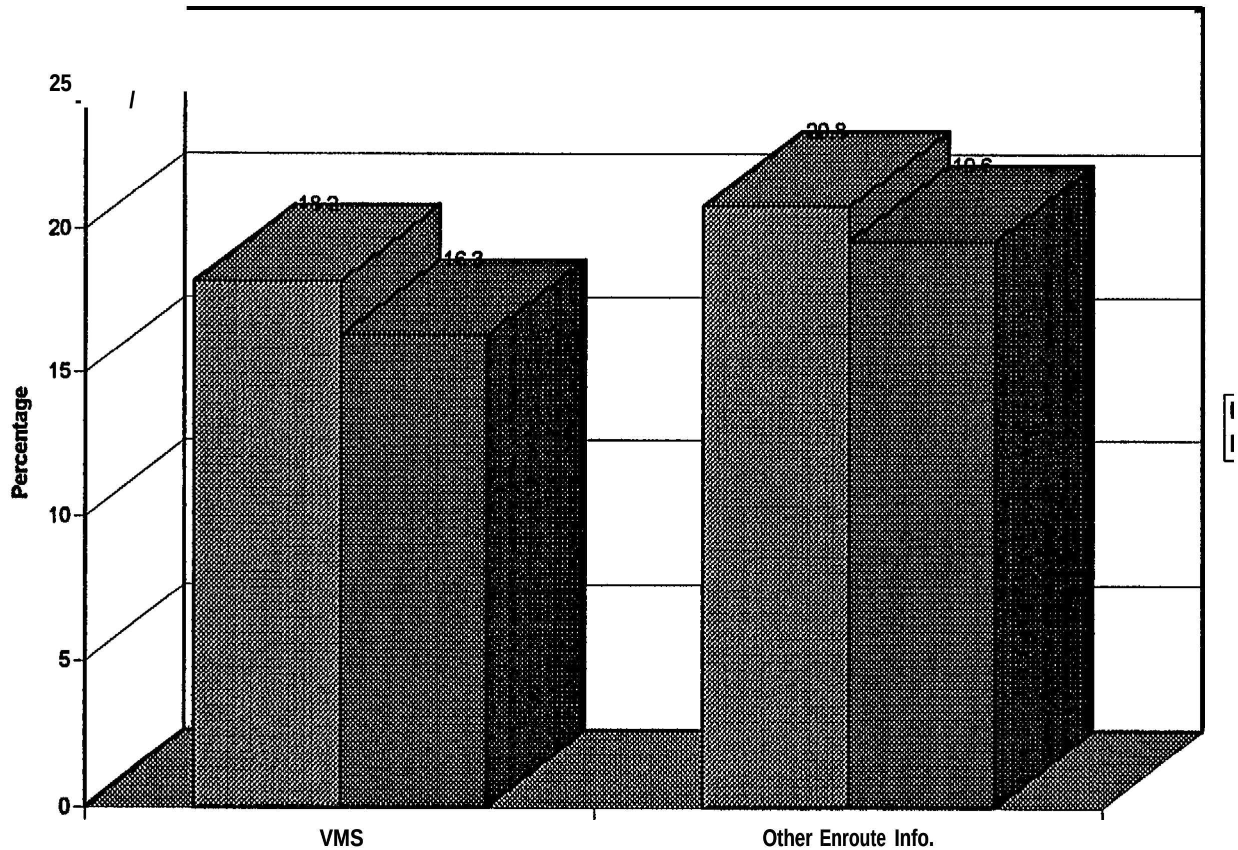

Figure 4.1: Percentage Reduction in HC Emissions Over the Base-Case for Normal Conditions

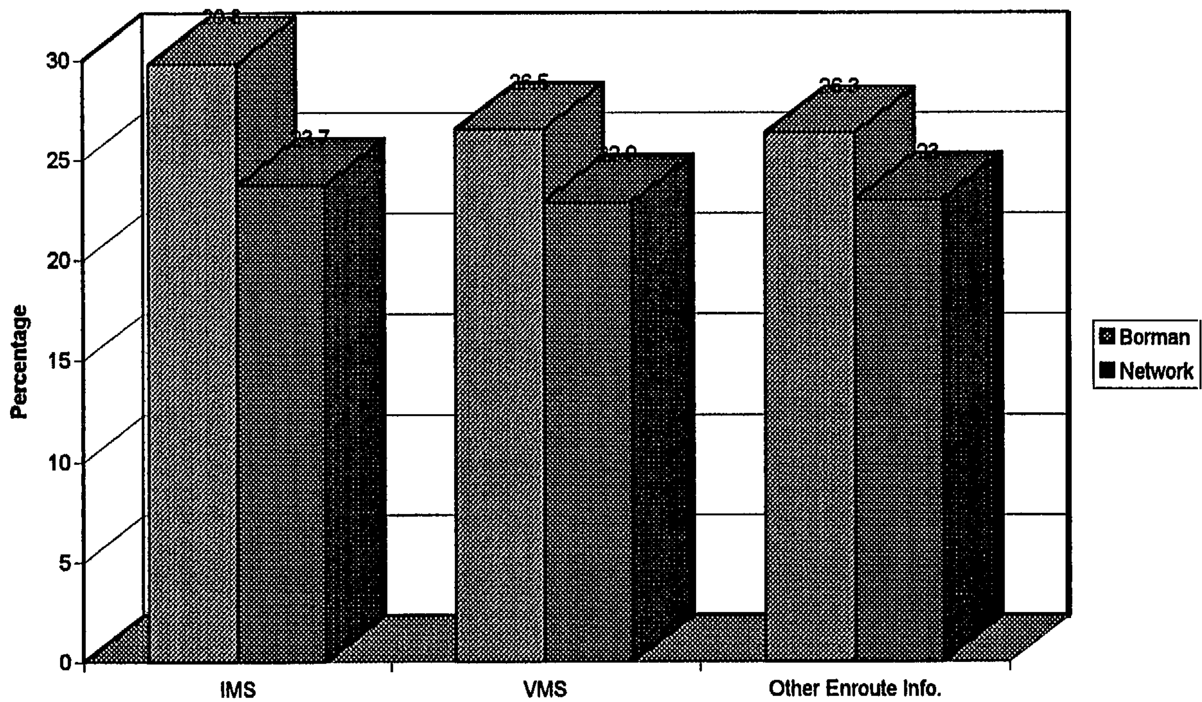

Figure 4.2: Percentage Reduction in HC Emissions Over the Base-Case for d Conditions (Lane-Closure)

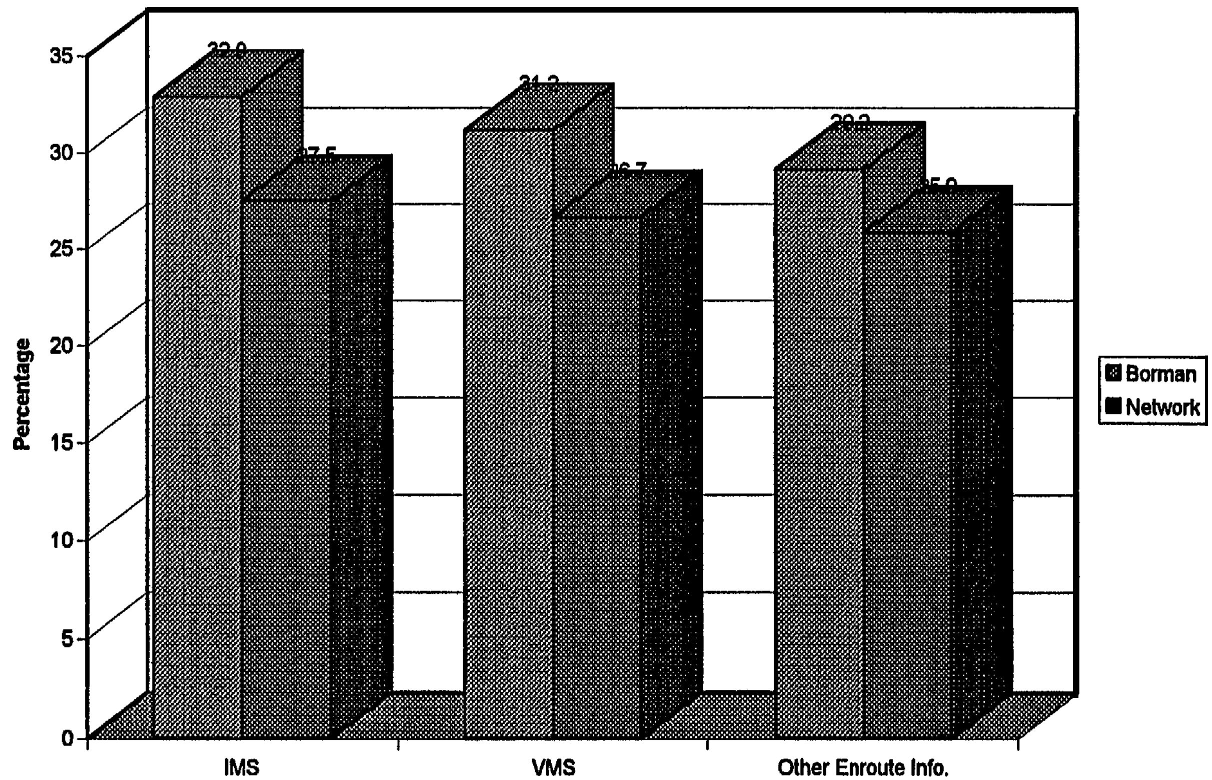

Figure 3 : Percentage Reduction in HC Emissions Over the Base-Case for ncident Conditions (Link-Closure)

4.2 CO Emissions

The emission trend of CO emissions is almost exactly the same as that of HC. It can be seen from Figure 4.4 that for normal conditions, higher reduction in network-level CO Emissions is achieved through providing enroute information to 60 percent of the users, as compared to that of VMS information. A similar kind of trend can be seen for CO emissions on Borman only, but it can be seen that the magnitude of reduction of CO emissions is higher on Borman as compared to that of the network. This is especially because the traffic on Borman uses the information provided by VMS to divert in case of congestion, leaving a relatively smoother flow of traffic on the expressway.

Figure 4.5 shows that in case of an incident blocking a lane on one of the links on Borman Expressway, the trend in emission reduction is same as that for the normal case. One noticeable point in this case is that IMS result in a higher reduction of CO emissions, as compared to enroute information and VMS. The comparison of Figure 4.1 and 4.2 shows that the magnitude of emissions reduction is higher in case of lane closure, as compared to the magnitude of emissions reduction under normal conditions.

The simulation results for the case of an incident blocking a link on Borman Expressway again show that IMS prove to be more effective in emission reduction under incident conditions, as compared to the other two components of ITS (Figure 4.6). Furthermore, it can be seen that the magnitude of emission reduction in this case is higher than that of the previous two cases.

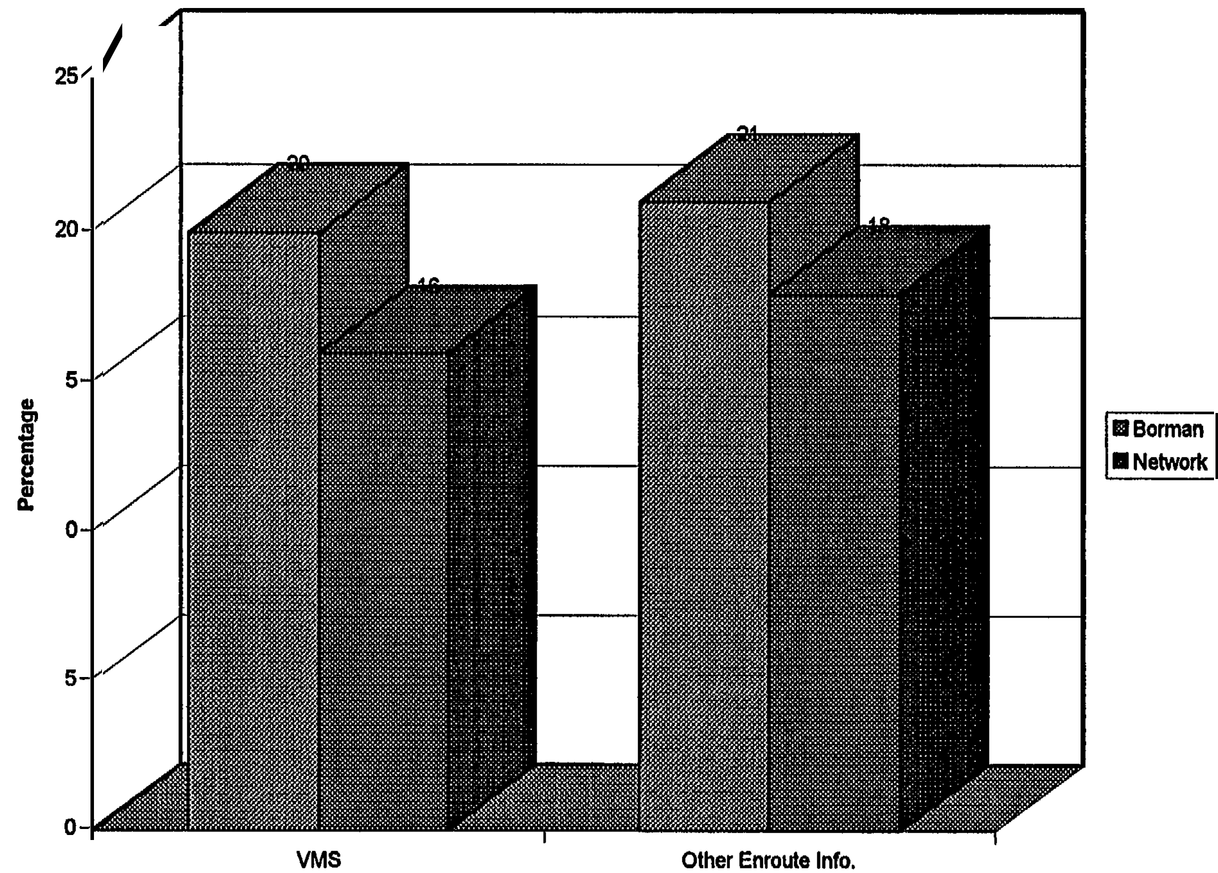

Figure 4.4: Per∞ ntage Reducti=n in CO Emissions Over the Base-Case for Normal Conditions

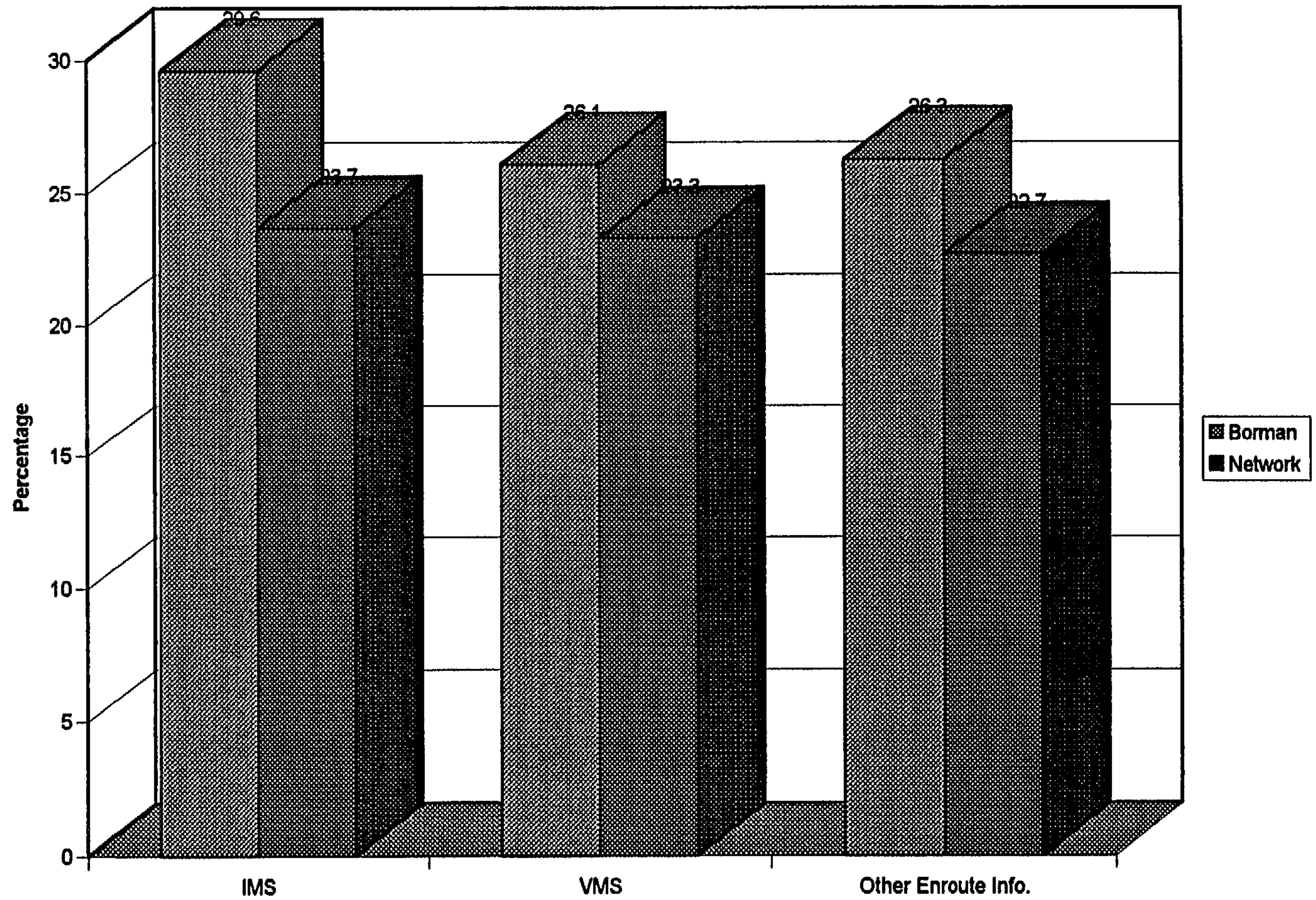

Figure 4.5: Percentage Reduction in CO Emissions Over the Base-Case for Incident Conditions (Lane-Closure)

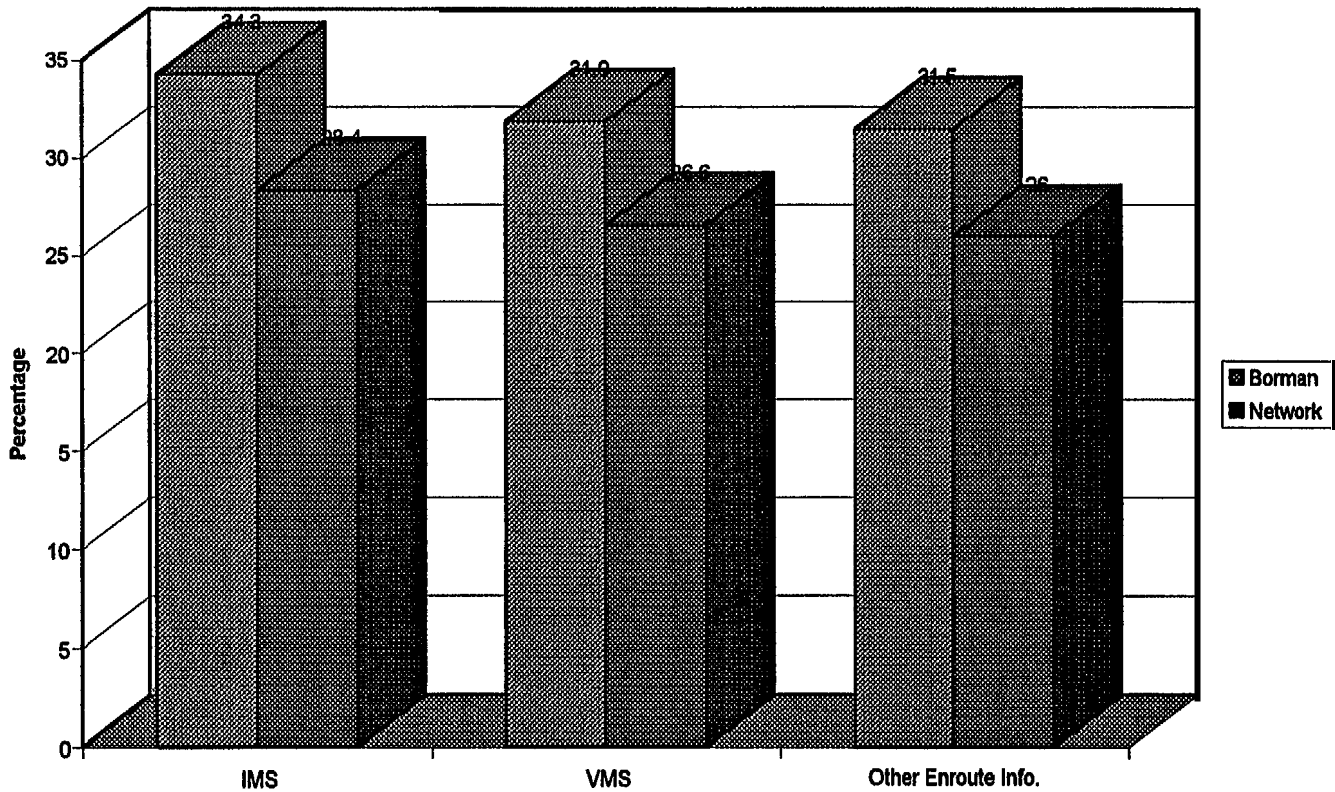

Figure 4.6: Percentage Reduction in CO Emissions Over the Base-Case for ncident Conditions (Link-Closure)

4.3 NOx Emissions

Unlike HC and CO, NOx emissions show quite a few variations, both in magnitude and in the trend. It can be seen from Figure 4.7 that VMS causes a higher reduction in NOx emissions as compared to enroute information. Secondly, the percentage of reduction of NOx emissions is higher for overall network, compared to Borman alone. This is due to the fact that NOx emissions are low at lower speeds. After diverting from the Borman, the traffic enters other links of the network causing a reduction in the average speed of the network links, and hence, lower NOx emissions.

Similarly, Figure 4.8 and 4.9 show that the network level reduction of NOx emissions is higher than the emission reduction on Borman. In addition to this, VMS proves to be the most effective ITS component in reducing NOx emissions, and unlike the case of HC and CO, IMS causes the lowest reduction in NOx emissions compared to the other components of ITS. It should be noted that the magnitude of NOx emission reduction is lower than that of CO and HC, showing that NOx is less sensitive to speed than CO and HC.

As in the case of HC and CO emissions, NOx emission reduction is more significant with incident conditions, as compared to the normal flow conditions. Figure 4-.7, 4.8, and 4.9 clearly show the trend and magnitude of NOx emission reduction for normal, lane closure, and link closure conditions with various ITS implementation scenarios.

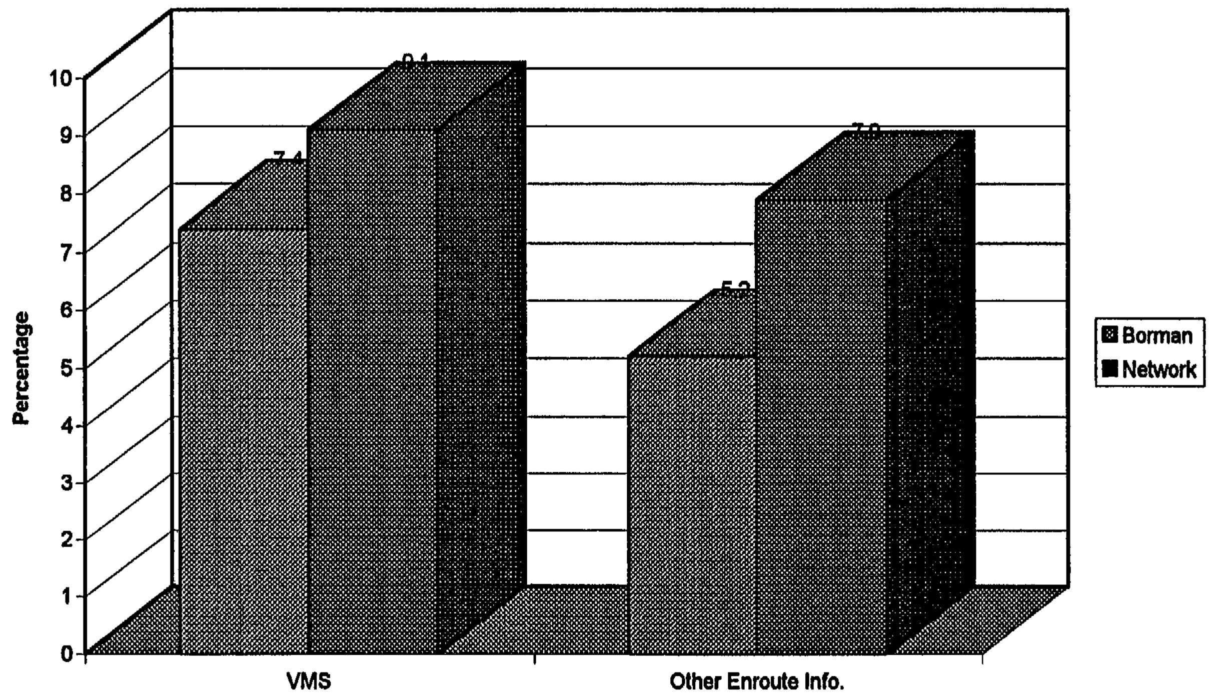

Figure 4.7: Percentage Reduction in NO_x Emissions Over the Base-Case for Normal Conditions

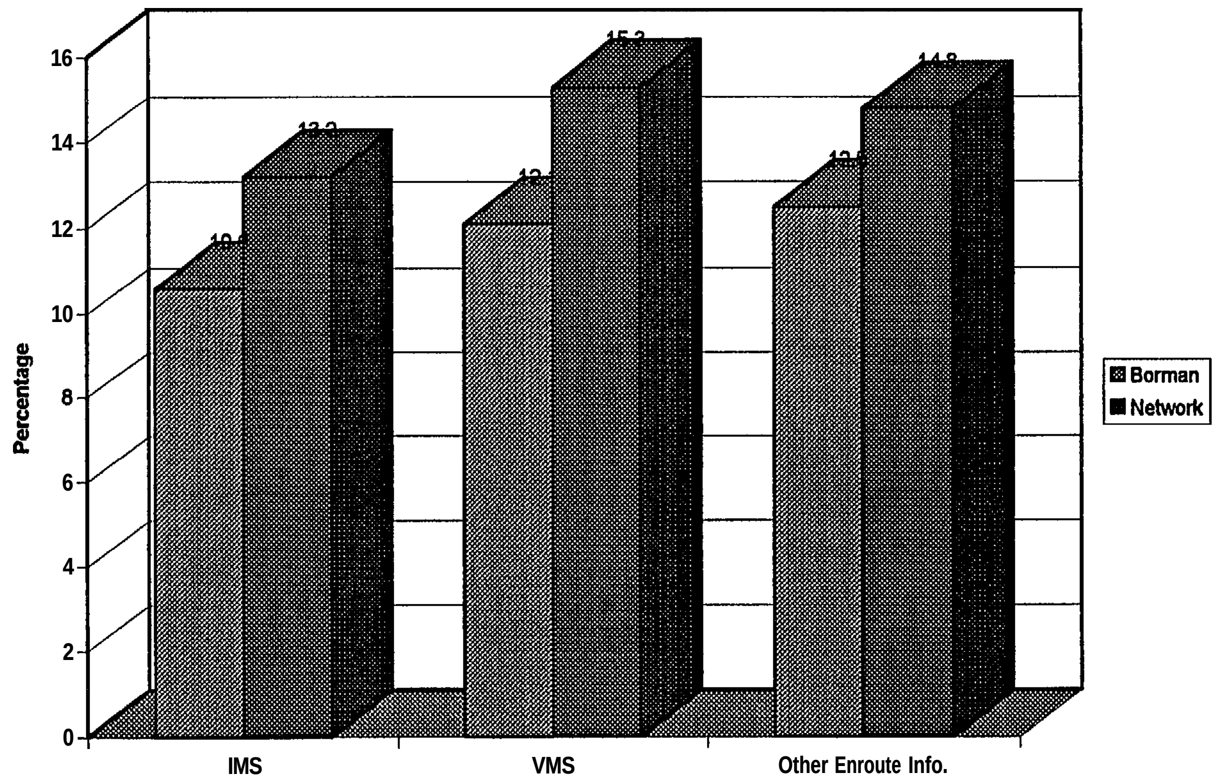

Figure 4.8: Percentage Reduction in NOx Emissions Over the Base-Case for Incident Conditions (Lane-Closure)

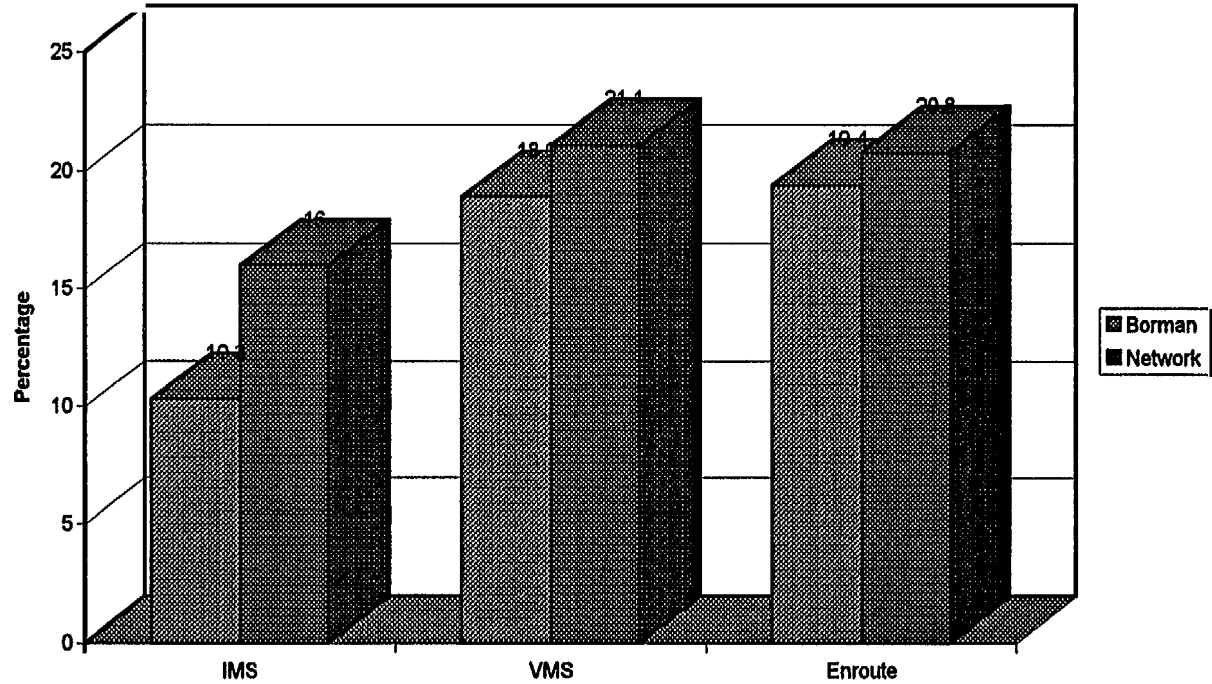

Figure 4.9: Percentage Reduction in NO_x Emissions Over the Base-Case for Incident Conditions (Link-Closur

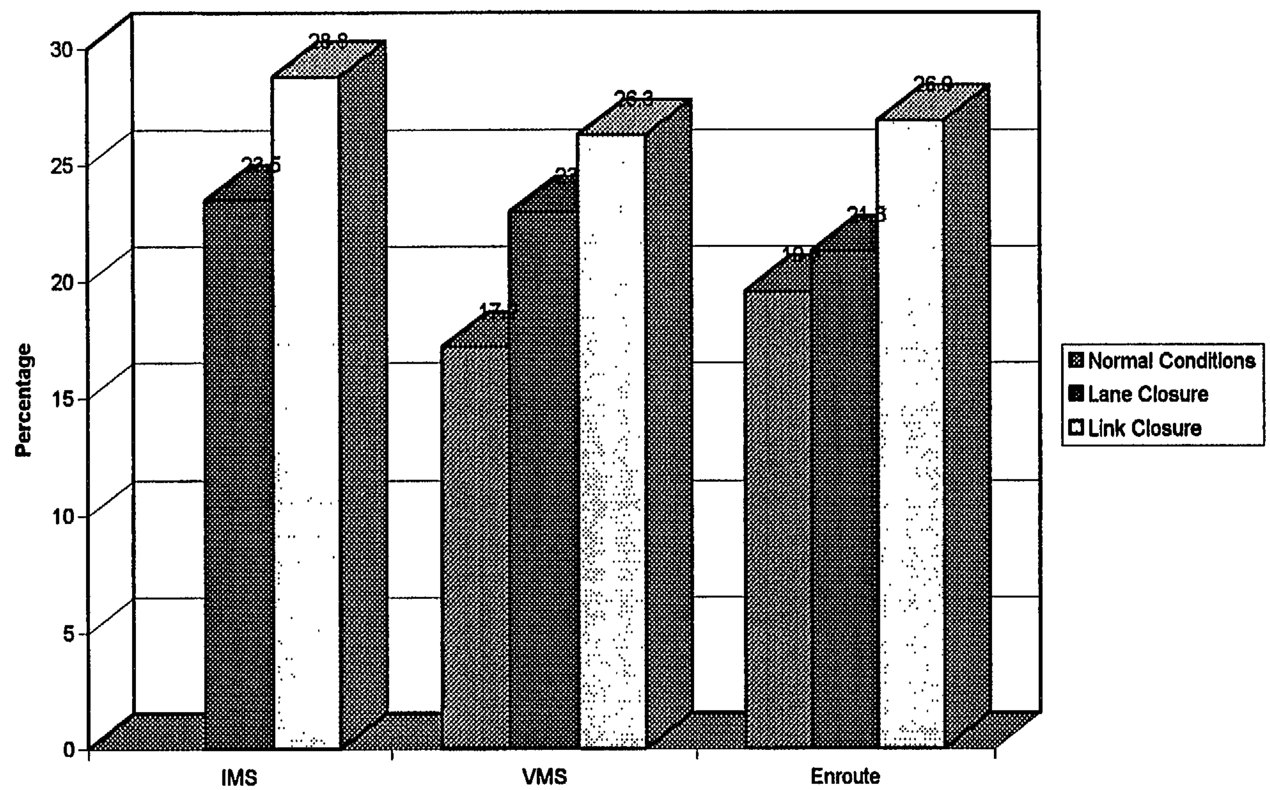

Figure 4.10: Percentage Reduction of Fuel Consumption over Base-Case for Various Scenarios

4.4 Fuel Consumption

The fuel consumption of the vehicles in the network is given in Table 4.2, and the percentage reduction under normal and incident conditions, for various ITS implementation scenarios is given in Table 4.6. From Figure 4.10, it can be seen that the maximum fuel consumption reduction percentage is achieved under link-closure conditions, followed by lane-closure, and normal conditions. In addition to this, the percentage reduction in fuel consumption is highest for IMS, followed by enroute information and VMS.

4.5 Sensitivity of IMS to Mobile Emissions

It can be seen from the results that IMS have a very high impact on the reductions of HC and CO emissions. It can also be seen that maximum benefits are obtained in case of link-closure conditions. That is why, sensitivity of incident duration reduction to mobile emissions for link-closure conditions was determined by the following simulation experiments.

As discussed in Section 3.3.2 , to simulate the effects of IMS, the incident duration was reduced by 50 percent. To determine the sensitivity of CO emissions with respect to the reduced incident duration caused by IMS implementation, simulation runs were made for incident duration reduction of 10, 20, 30, and 40 percent. The rest of the conditions simulated for these experiments were same as described in Section 3.3.2. The results obtained from these simulation runs are shown in Figure 4.11.

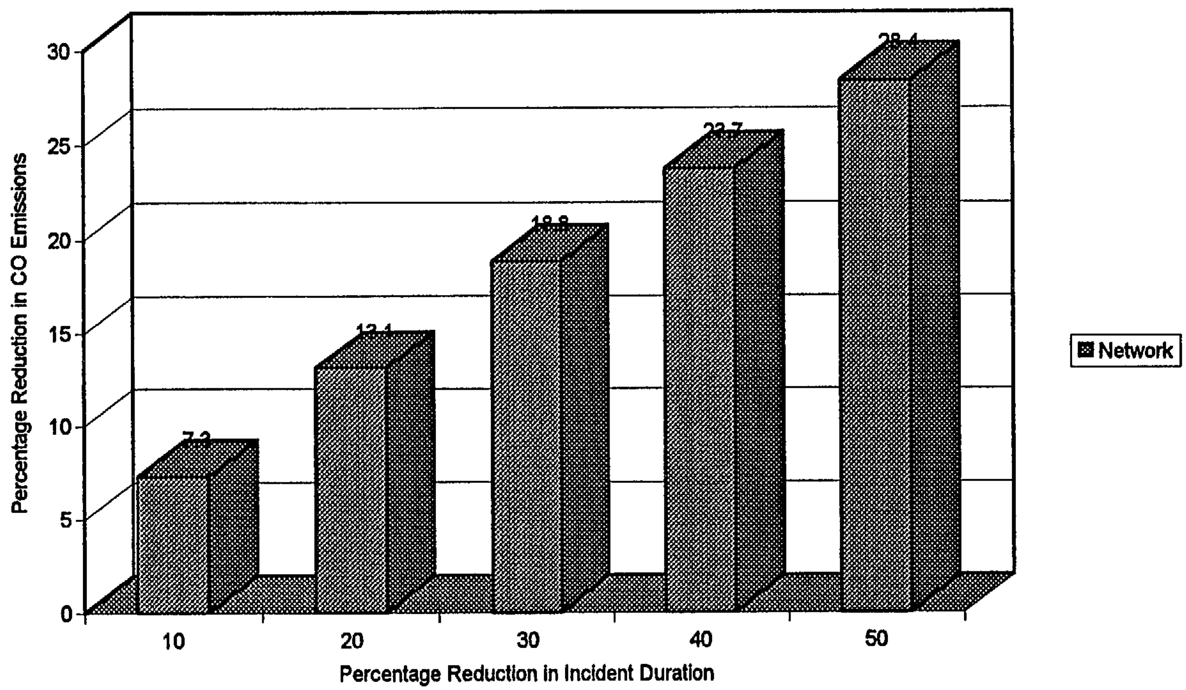

Figure 4.11 : Sensitivity of Percentage Reduction in Incident Duration Due to IMS Implementation, to Percentage Reduction in Network-Level CO Emissions for Link-Closure Conditions

4.6 Discussion

The above given results clearly show that ITS technologies such as IMS, VMS, and other enroute information, improve the flow of traffic, and aid in decreasing HC and CO emissions, and the network fuel consumption by increasing the average speed of the network. It was also observed that the emission reduction benefits from ITS are more significant for incident conditions, as compared to the normal traffic conditions. Furthermore, the reduction in NOx emissions is inversely proportional to the average speed of the flow, and NOx emissions are higher aroundfreeways than around arterials.

5. SENSITIVITY ANALYSIS

In order to better understand the transportation-related air quality problems, it is necessary to understand the sensitivity of mobile emissions to important traffic flow characteristics and composition. This chapter elaborates the sensitivity of vehicle speed, truck percentage, and number of stops on to HC, CO and NOx emissions on Borman Expressway. The results are tabulated in Tables 5.1, 5.2 and 5.3 and are graphically represented in Figures 5.1, 5.2 and 5.3.

5.1 Vehicle Speed

The sensitivity of vehicle speed to emissions was captured by using EPA's emission software, MOBILES. HC, CO and NOx emission factors were found for average speeds ranging from 5 mph to 65 mph, with twelve increments of 5 mph each, keeping all other factors constant. This reflects increasing average speed, from congested to the free-flow state on Borman Expressway. The vehicle composition was kept same as that on the Borman. As can be seen from Figure 5.1, the curve for HC emissions shows that HC emissions are highest at 5 mph and lowest at 55 mph. The decline in emissions is very sharp from 5 to 20 mph, and it goes down further till 55 mph with a lower declination. It can also be seen that the rate of increase of emissions from 55 to 65 mph is relatively low.

The trend for CO emissions is almost similar to that of HC emissions. From Figure 5.1, it can be seen that CO emissions are maximum at 5 mph and minimum at 50mph. The rate of decrease of CO emissions is same as that of HC emissions from 5 to 50 mph, but after that, the rate of increase of CO emissions from 50 to 65 mph is substantially high, as compared to that of HC emissions.

The emission curve for NOx with respect to vehicle speed shows a very diierent trend from that of CO and HC. Figure 5.1 shows that NOx emissions are low at lower speeds and high at higher speeds. It can be seen that NOx emissions are lowest for 25 mph and highest for 65 mph, and the curve is relatively flat from 20 to 40 mph.

5.2 Truck Percentage

Another factor that can result in variation in emissions is the percentage of trucks in the traffic volume. Borman Expressway has very heavy truck traffic ranging from 12 to 40 percent. To study this effect, HC, CO and NOx emissions were found for diierent percentages of trucks using MOBILES, keeping all other factors, constant. The average speed was used was same as that on Borman Expressway. The percentages used were from 5 to 95, with eighteen increments of 5 percent. It was assumed that all other vehicles in the total volume were passenger cars. Figure 5.2 shows that there is a linear relationship between the percentage of trucks and emissions. It can also be seen that HC and CO emissions are high at low truck percentage and low at high truck percentage. The trend is opposite for NOx, which shows that NOx emissions increase with increasing truck percentage.

Table 5.1 : Sensitivity of HC, CO and NOx Emissions to Vehicle Speed on Borman Expressway (using MOBILES)

Vehicle Speed (mph)	**HC** Emissions (gms/mile)	CO Emissions (gms/mile)	NOx Emissions gms/mile)
5	13.56	99.58	3.31
10	7.59	55.76	2.89
15	5.73	40.46	2.67
20	4.58	32.56	2.55
25	4.02	26.72	2.54
30	3.64	22.81	2.55
35	3.35	20.06	2.57
40	3.12	18.07	2.62
45	2.94	16.63	2.69
50	2.82	15.98	2.92
55	2.77	16.12	3.37
60	2.98	26.92	3.89
65	3.21	37.89	4.49

Table 5.2: Sensitivity of HC, CO and NOx Emissions to Truck Percentage on Borman Expressway (using MOBILES)

Truck Percentage	HC Emissions (gms/,ile)	CO Emissions (gms/mile)	NOx Emissions (gms/mile)
5	2.81	32.49	3.88
10	2.72	31.17	4.87
15	2.63	29.84	5.87
20	2.53	28.52	6.87
25	2.44	27.20	7.87
30	2.35	25.87	8.87
35	2.26	24.55	9.87
40	2.17	23.22	10.87
45	2.08	21.90	11.86
50	1.99	20.57	12.86
55	1.90	19.25	13.86
60	1.81	17.92	14.86
65	1.72	16.60	15.86
70	1.63	15.28	16.86
75	1.54	13.95	17.86
80	1.45	12.63	18.85
85	1.36	11.30	19.85
90	1.27	9.98	20.85
95	1.18	8.65	21.85

Table 5.3 Sensitivity of HC, CO and NOx Emissions to Number of Stops on Borman Expressway (using INTEGRATION)

Number of Stops	HC Emissions (gms)	CO Emissions (gms)	NOx Emissions (gms)
17924	65352	311740	34869
17932	65279	311510	34828
17956	65642	312981	35 126
18191	65903	3 14024	35203
18455	67445	323 164	36323
18609	67895	324799	36607

5.3 Number of Stops

Another important factor giving rise to high emissions and accounting for congestion is the number of vehicle stops. This effect captures the increase in emissions due to greater accelerations and decelerations in the traffic flow. The values of HC, CO and NOx emissions were obtained from different half-hour simulation runs on the Borman network, using INTEGRATION simulation model. The resulting emission trends are shown in Figure 5.3. It can be seen from the figure that HC, CO and NOx emissions increase with the increase in the number of stops. The figure also shows that there is a sharp increase in emission of all the three pollutants for number of stops greater than 18191. This factor is very important in considering the impacts of ITS on air quality, where the reduction in emissions due to smoother flow can be captured.

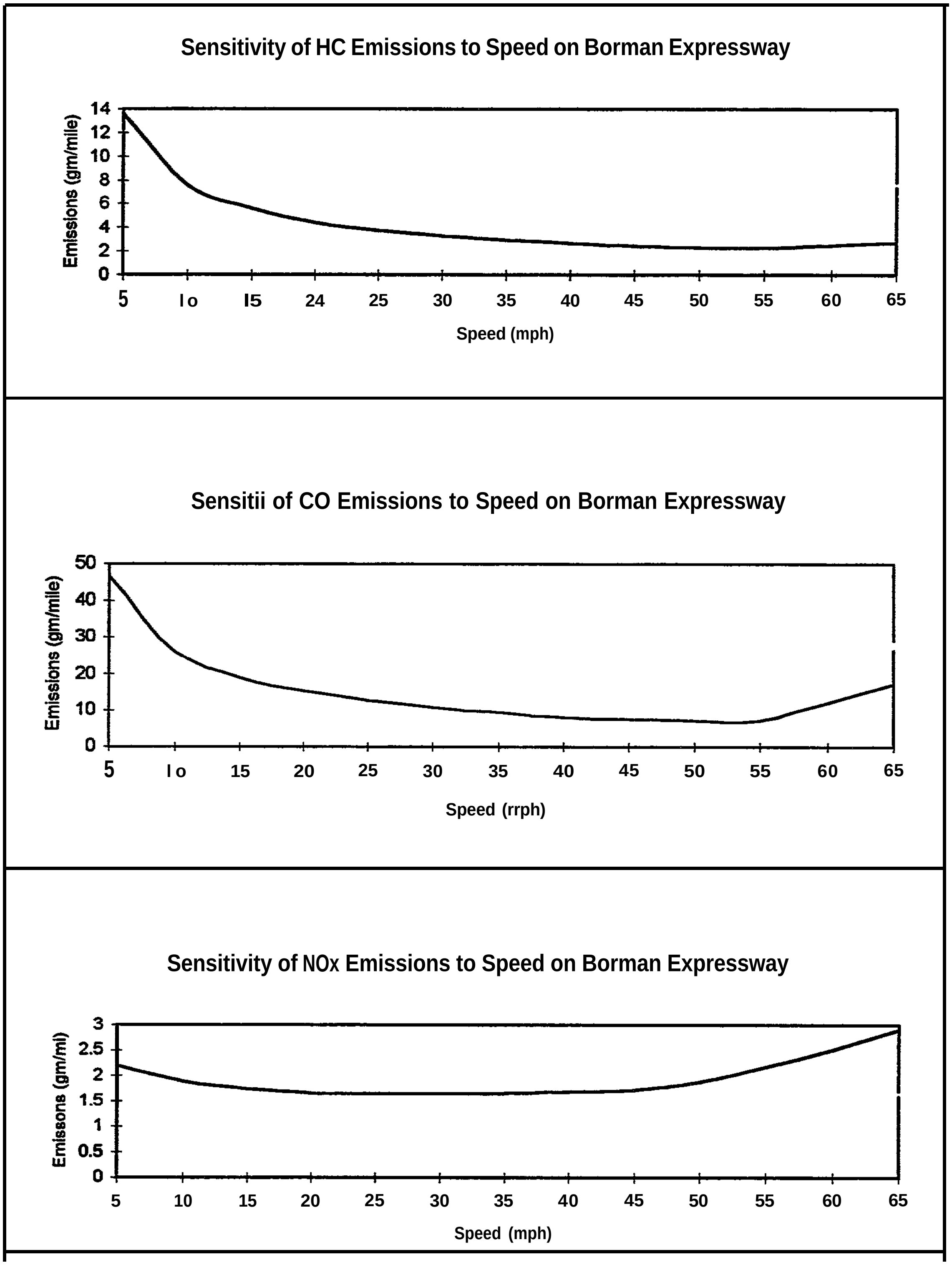

Figure 5.1 : Sensitivity of HC, CO and NOx Emissions to Speed on Borman Expressway (using MOBILES)

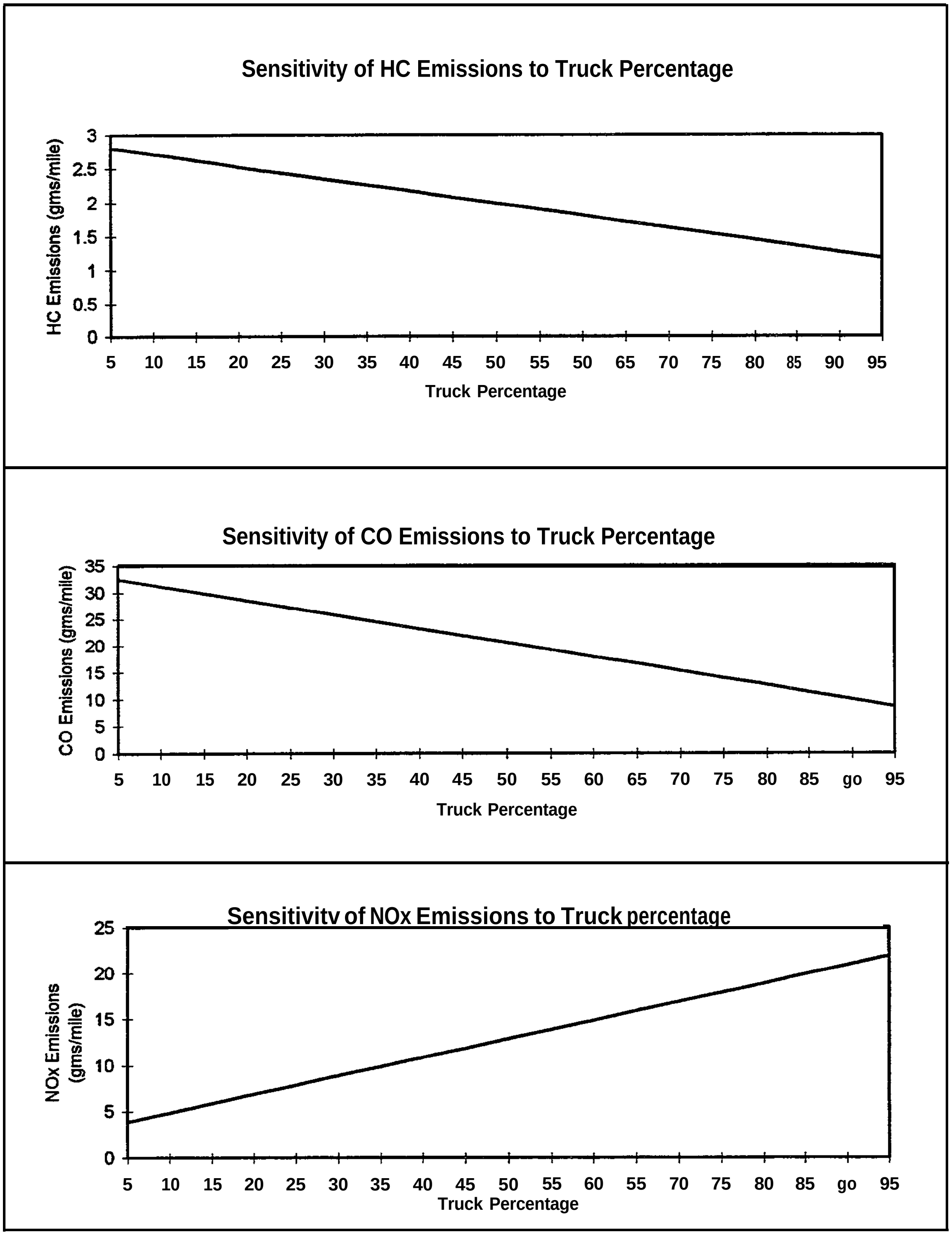

Figure 5.2 : Sensitivity of HC, CO and NOx Emissions to Truck Percentage on Borman Expressway (using MOBILES)

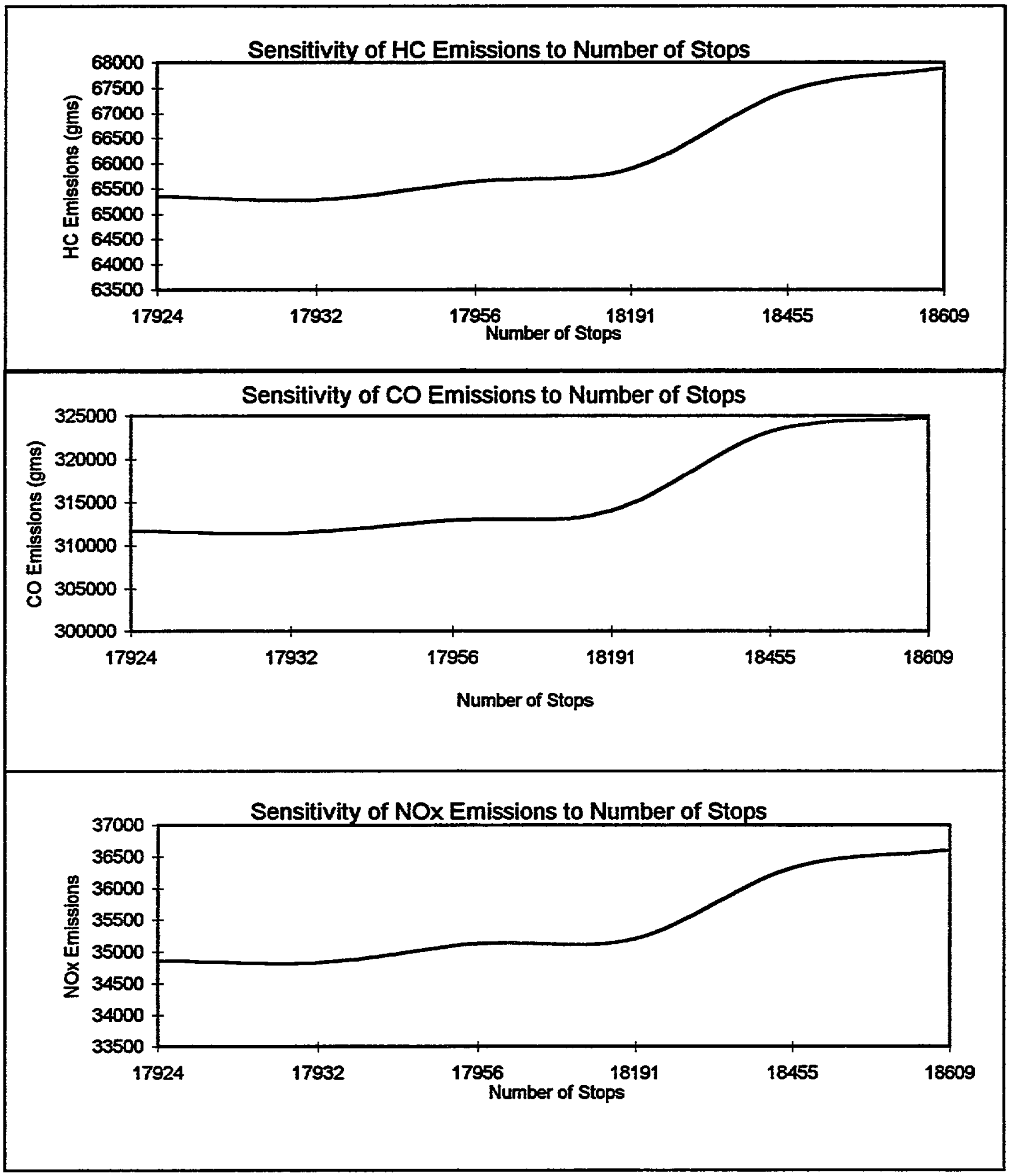

Figure 5.3 : Sensitivity of HC, CO and NO_x Emissions to Number of Stops on Borman Expressway (using INTEGRATION)

5.4 Discussion

It can be gathered from the above given sections that mobile emissions are highly sensitive to vehicle speed, number of stops, and percentage of trucks in the traffic flow. It is very clear that NOx emissions show very different behavior with respect to change in speed. Unlike HC and CO, NOx emissions are lower at low speeds and vice versa. It was also observed that increase in number of stops in a given traffic flow increases the HC, CO and NOx emissions. Furthermore, it can also be seen that an increase in the percentage of trucks results in a substantial increase in NOx emissions, indicating higher NOx emissions on Borman due to high truck percentage. Hence, it can be clearly seen that if an incident occurs on Borman Expressway, the resulting lower average speed and higher number of stops will results in high emissions.

6. CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

The results obtained from the simulation experiments indicate that significant improvement in air quality can be achieved by effective implementation of various ITS technologies under normal and incident conditions. The results also show a marked reduction in network-level fuel consumption due to the simulation of IMS, VMS and other enroute information to users under normal and incident conditions.

It was seen that in case of HC and CO, the emission reduction was higher on Borman alone as compared to the network-level emission reduction. On the other hand, the NO, emission reduction on Borman alone was lower compared to that of the network-level NO, emission reduction. This is consistent with the HC, CO and NOx emission trends shown in Figure 5.1, indicating that HC and CO emissions have an inverse relation with the average speed, while NOx emissions show a direct relation with the average speed of traffic flow.

It was observed that for normal peak-hour conditions, maximum reduction in HC and CO emissions can be achieved by providing enroute information to 60 percent of the users, while maximum reduction in NOx emissions can be achieved by using the VMS arrangement, as shown in Figure 3.3. Incase of lane-closure conditions, the maximum reduction in HC and CO emissions were seen from IMS implementation, while VMS still proved to be the most effective for NOx emissions reduction under these conditions. Simulation for link-closure conditions indicated maximum reduction in HC, CO and NOx emissions for all the three air pollutants emitted by motorized vehicles.

One important trend observed from the results of these experiments is that the magnitude of reduction in mobile emissions is highest under incident conditions with link closure, and lowest under normal peak-hour conditions. This is because, the heavy flow of traffic on the Borman causes huge backups due to lane or link closures, and the reduction in incident duration due to implementation of IMS, such as the assistance of Hoosier Helpers, creates a heavy impact on reducing congestion, and in turn, mobile emissions.

Hence it can be concluded that in addition to resulting in improved traffic flow, lower travel times, and lower fuel consumption, effective implementation of various ITS technologies can cause a marked reduction in mobile emissions, leading towards improved air quality, and a clean and healthy environment.

6.2 Future Work

The simulation duration of the experiments done for evaluating the ITS impacts on air quality was 30 minutes for each scenario. These simulation runs were made by using the medium version of the INTEGRATION simulation software. Using the large version of INTEGRATION for this network allows the user to increase the simulation duration, depending on the size of the network. To capture the variation in traffic flow during the peak period, need exists to simulate the experiments for a higher duration, covering both the morning and the evening peak periods. It will further allow the user to run the simulation experiments for several times to prove the statistical significance of the results. In addition to this, there is a need for developing a model based on a database collected on Borman Expressway, listing the emission levels, and the corresponding speed of flow, traffic volume, temperature, and other important traffic and meteorological variables. This will not only result in obtaining highly accurate emission estimates for Northwestern Indiana, but will also satisfy the need for having an emission model based on a database capturing actual traffic conditions.

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SECTION - III

EVALUATION OF ITS IMPACTS ON SAFETY

1. INTRODUCTION

1.1 Motivation for the Research

Although road travel in the United States is the safest of any industrialized nation, traffic crashes continue to impose a $150 billion burden annually on the country's economy (Roadway Safety Foundation, 1996). In addition to fatalities, injuries, and property damage, motor vehicle crashes also create significant delays, contribute to air pollution, and, most importantly, expose other motorists to the threat of sustaining a secondary crash. A secondary crash is defined as a crash that is the direct or indirect result of a prior incident.

According to the National Highway Traffic Safety Administration (NHTSA) General Estimates System (GES), in 1991 there were an estimated 6.1 million police-reported crashes in the U.S. Figure 1.1, which is taken from the Fatal Crash Reporting System (FARS), shows that rear-end crashes are the most numerous of the six crash types. These include rear-end, single-vehicle roadway departure (SVRD), backing, lane change/merge (LCM) drowsy/fatigued driver-related, and signalized intersection/straight crossing path (SVSCP) crashes. Close examination of the rear-end crashes revealed that 70% collided with a stationary lead vehicle.

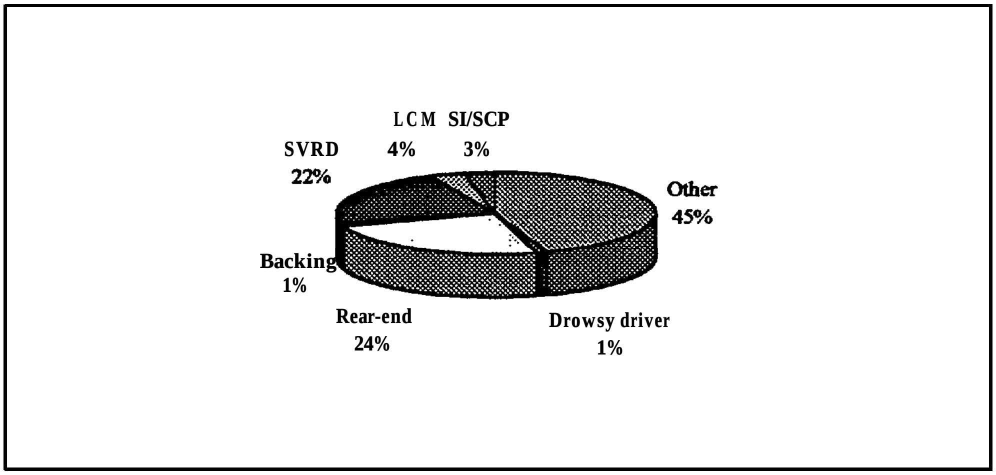


Figure 1.1 Distribution of Crashes by Crash Type

The crash assessment statistics can lead us to conclude that a large percentage of crashes can be avoided by eliminating rear-end or secondary crashes. In fact, initial safety research associated with Automated Highway System projects indicated that the deployment of advanced technologies would likely have a very positive impact on fi-eeway crashes, estimating the minimum reduction of secondary crashes at about 30% (Preston (1996)).

Rear-end crashes can be avoided by utilizing Intelligent Transportation Systems (ITS) technologies such as Advanced Traffic Management Systems (ATMS). ATMS applies to advanced and emerging technologies used to improve surveillance, incident detection, and traveler information. When ATMS technologies are effectively integrated and deployed in surface transportation, a number of benefits are realized, including an efficient use of infrastructure, and significant improvements in mobility, accessibility, and safety (ITS America (1995)). The FARS report highlighted driver inattention to the road and traffic as the most common contributing factor associated with secondary crashes. Following the lead vehicle too closely was the second highest contributing factor of secondary crashes. ATMS technologies would serve not only to improve the time it takes to clear incidents from the roadway, but also to inform drivers of stationary vehicles and other incident debris in their forward path and to increase their headways and reduce their speeds.

The main objectives of this research were as follows:

1. To develop a methodology to test the hypothesis that secondary crashes may take place as a direct or indirect result of primary incidents.
2. To use models to predict the likelihood of a primary incident being followed by a secondary crash.
3. To suggest the potential role of ITS technologies in reducing secondary crash likelihood.

A primary incident is any event that has the potential to disrupt traffic flows by creating queues and accelerating and decelerating shock waves, which increase the risk of a secondary crash. A secondary crash is one that can be attributed to a prior (primary) incident. Primary incidents on roadways include crashes, overheating vehicles, and spills or other debris on the lanes or shoulders.

Prior to this research, other authors such as Raub (1997), Knipling (1993), Roberts et al. (1993), and Owens (1978), have conducted studies which focused on determining whether the cause of some crashes could be attriiuted to an earlier incident. Their reports have linked primary incidents with the occurrence of secondary crash events.

Other studies focused on the primary incidents themselves, particularly incidents that are crashes. Madanat et al. (1993) used environmental and traffic characteristics to predict the likely occurrence of primary crashes, while Ivan et al. (1997), and Skabardonis et al. (1997) focused on using environmental and traffic characteristics to predict the rate at which primary crashes occur. Despite these studies, there appears to be little work on identifying the primary incident characteristics that increase the likelihood of secondary crash occurrence.

In order to test the hypothesis that secondary crashes are the result of primary incidents, incident data for the Borman Expressway was used in the present study. The Borman Expressway is a 16 mile stretch of I-80/94 in northwestern Indiana, and incidents recorded on the freeway from September 1991 to January 1996 were used in the research. Starting with an initial set of 18 descriptors of the primary incident, this research employed a logistic regression approach to the Borman Expressway incident database to develop the methodology to predict the likely occurrence of a secondary crash on freeways.

The apparent random nature of primary incidents on roadways hides the true impact they have on secondary crashes and on the overall safety of the roads. The rather unpredictable timing and location of incidents is one of the principal reasons they are so diiicult to manage by both the responding agencies and the public. This is particularly true for heavily trafficked highways, because as traffic volumes continue to increase, so do the frequency and impacts of incidents. This research attempted to examine primary incidents and identify the characteristics that increase their impact on secondary crash occurrence.

Using the assumptions that primary incidents and the secondary crashes they cause are related in time and space, the secondary crashes in the database were identified. These criteria, which are described in Chapter 3, revealed that 2% of reported incidents on the Borman Expressway could be classified as secondary crashes. However, closer examination of crashes reveals that approximately 35% of all crashes could be classified as secondary crashes. It is apparent that most of the traffic disrupting primary incidents on the Borman Expressway are crashes, therefore a decision was made to use only the crash data to predict the likely occurrence of a secondary crash. It should be noted that the methodology developed in this study to predict secondary crash occurrence is flexiile and can be used with an incident or a crash database.

1.2 Background of the Study Area

The crash database used in this study was generated from an incident data set compiled by the Hoosier Helper freeway service patrol (FSP) in northwestern Indiana. Operating under the jurisdiction of the Indiana Department of Transportation (INDOT) the Hoosier Helper program maintains a six-vehicle fleet that patrols a 16-mile stretch of Interstate 80/94 near Gary, Indiana, known as the Borman Expressway. The objective of the FSP is to look for, and respond to, incidents.

The Borman Expressway is a heavily trafficked, six-lane, east-west corridor that is part of the 130 mile Gary-Chicago-Milwaukee (GCM) ITS priority corridor. ITS technologies being tested on the Borman Expressway include detectors, closed-circuit television (CCTV) cameras, highway advisory radios (HAR), variable message signs

(VMS), and the freeway service patrol. ITS technologies are important on the Borman Expressway where peak periods have extended from two 2-hour periods during the morning and afternoon, to the entire weekday, thus diminishing the ability of the Expressway to absorb the capacity reductions caused by incidents. The most important component of the Borman incident management system is the Hoosier Helper freeway service patrol (FSP) program. The Hoosier Helper FSP records over 7000 incident assists on the Borman every year, which include providing information, fuel and water to stranded motorists, changing tires, removing debris from the roadway, and, most importantly, providing support at crash sites. Crash site support includes alerting emergency service crews, removal of lane-blocking vehicles, and restoration of ‘normal’ traffic flow.

The Hoosier Helper incident database used in this research is valuable to secondary crash likelihood analysis because of the large number of secondary crashes recorded, the extent of the database (September 1st 1991 to January 22nd 1996), and the detail of the incident characteristics.

1.3 Organization of this Section

The remainder of this section is organized as follows. Chapter 2 discusses safety, safety analysis methods, as well as ITS and ATMS technologies and their safety benefits. Chapter 3 describes the incident database and outlines the processing and development of the crash database. In Chapter 4, the theory of logistic regression models is briefly introduced and a series of models are estimated. The first model assumes a general clearance time, while the second assumes two separate clearance times: one specific to winter and the other specific to the remaining seasons. Chapter 5, the concluding chapter, identifies ITS technologies that can either be implemented or improved in order to improve safety on the Borman Expressway. Chapter 5 also presents the policy implications of the models and makes recommendations for future research.

2. LITERATURE REVIEW

2.1 Safety

Gunnarsson (1996) states that roadway safety may be defined as the acceptability of risk, where risk is further described as the consequence of a crash or the Probablity that a crash will happen. A roadway is safe if its risks are judged to be acceptable.

A crash is an undesirable, suddenly occurring event that results in human and material losses. Motor vehicle crashes create significant delays, increase road maintenance costs, contribute to air pollution, consume energy, and negatively impact roadway safety. Several factors, including facility type, weather, geometric characteristics, and degree of congestion may contribute to the number and severity of crashes in a network (Roadway Safety Foundation (1996)).

In the context of the present study, a crash is termed primary if it is the main cause of an incident. A crash is deemed secondary if it is not independent from, or its occurrence can be attributed to, a primary or an earlier crash. Numerous references to secondary crashes were found in the literature (Raub (1997), Skabardonis et al. (1997), Al-Deek et al. (1993), Judycki et al. (1992), Tedesco et al. (1992), and Owens (1978)), however only two studies actually quantified secondary crashes (Raub (1997) and Owens (1978)). As early as 1978, Owens conducted a videotaped incident study on limited access British freeways, and concluded that 17 percent of the crashes recorded could be related to an earlier incident. Raub (1997) completed analyses of incidents and crashes on an urban arterial in northern Chicago, the results of which suggested that 15.5 percent of the crashes in that study were secondary crashes.

While the results of the Raub (1997) and Owens (1978) studies support each other, the results are shy of the 34.5% seen in the Borman data. This could be attributed to the following. The two studies spanned periods of less than a month. The Owens study covered 29 days during July, August, and September of 1978, while the Raub study lasted 27 days from January 9 to February 5, 1995. It is entirely possible that the study periods were not long enough to capture the incident characteristics. In addition, the study by Raub was conducted during the winter months, a period of low traffic volumes, while the Owens study was completed during an era of significantly lower volumes and consequently lower risk. The Borman, on the other hand, experiences a large number of multiple vehicle crashes due to the volumes and the speeds at which the vehicles travel.

In a California study which analyzed crash data for the years 1989, 1990 and 1991, Tedesco et al. (1996) developed a safety model to estimate crashes based on facility type, crash type and level of congestion, and found that the crash rate increased by 605% in the presence of an earlier crash. The study stated that the potential for a crash occurring increases in the presence of an earlier crash, due to the increased congestion conditions. Skabardonis et al. (1997) Al-Deek et al. (1993), and Judycki et al. (1992) agree in principle that a portion of crashes could be linked to an earlier incident or crash. However, these studies did not provide figures to support their claims.

2.2 Safety Analysis Methods

Baker (1960) noted that while some of the chief causes of a crash can be observed in crash investigations, there is no single evident cause of a crash, and systematic analyses are therefore necessary. Fortunately, although uncontrolled and unpredictable, crash events can normally be explained and treated in both an analytical and systematic way. Crashes indeed have been analyzed using several diirent methods and explanatory variables, and this section serves to examine the techniques and models previously used.

Most of the existing safety models were developed to predict primary crash rate, or the likely occurrence of a primary crash. Researchers have generally used three approaches to primary crash rates based on traffic geometric, and environmental variables. They include multiple linear regression (ALDeek et al. 1993, Joshua et al. 1990), Poisson regression (Ivan et al. 1997, Skabardonis et al. 1997, Hadi et al. 1995), and binary logit modeling (Madanat et al. 1996).

Al-Deek et al. (1993) used linear regression to model annual crash rates with crashes observed over a two and a half year period, from January 1990 to June 1992, on a 25-mile segment of I-4 in Orange County, Florida. This study found that the square root of the annual crash rate was related to the following explanatory variables: the average hourly traffic volume, the section length times the number of lanes, the percent of time when no queues exist, and the total number of on- and off-ramps in the segment.

Mohamedshah et al. (1993) conducted a study of over seven thousand miles of roadway logs in the state of Utah and used linear regression to predict the truck crash involvement rate per kilometer per year based on AADT per lane, truck ADT per lane, shoulder width, horizontal curvature, and vertical gradient. This study found that the truck involvement rate increases with AADT, truck ADT, degree of curvature and gradient.

Ivan and O'Mara (1997) used Poisson regression to predict traffic crashes in Connecticut usiig crash data from January 1, 1991 to December 31, 1993. This study concluded that traffic crash rates were affected by speed limit and annual average daily tragic (AADT). Another study by Skabardonis et al. (1997) used the Poisson distribution to predict the frequency of incidents on I-880 in California. This study reported that the variables, time-of-day, day-of-the week, presence of shoulders, traffic volumes, and weather conditions, accounted for most of the variability in the incident occurrence.

An earlier study by Madanat et al. (1996) on incident data for 1992 on the Borman Expressway used binary logit models to predict the likelihood of vehicle crash incidents. The study discovered that the likelihood of a primary crash was affected by the location of the vehicle relative to on/off ramps, and the discrete variables rain and visibility.

Models that predict secondary crash rates, or the occurrence of secondary crashes, are not abundant in the literature. The study by Tedesco et al. (1996) calculated crash rates for different time periods in order to determine the relationship between crash rate and level of congestion. The paper reported that crash rate increases with volume/capacity ratio. Further, secondary crashes were defined as those crashes that occurred within one hour and one mile upstream from the primary crash during peak periods (half mile during off-peak periods). Calculation of the secondary crash rates revealed that the secondary crash rate increases the crash risk by 605%.

2.3 Safety Benefits of ITS

Intelligent Transportation Systems (ITS) is composed of a number of technologies, including information processing, communications, control, and electronics. Combining these technologies with transportation systems can result in improved safety, reduced congestion, enhanced mobility, reduction in environmental impact, energy savings, and the promotion of economic productivity. The different ITS technologies can be applied to six functional areas:

- Advanced Traffic Management Systems (ATMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Vehicle Control Systems (AVCS)
- Commercial Vehicle Operations (CVO)
- Advanced Public Transportation Systems (ARTS)
- Advanced Rural Transportation Systems (ARTS)

ATMS, of which incident management systems is a part and is the focus of the present study, employs technologies and traffic management and control systems in order to respond in real-time to dynamic traffic conditions. The mission of ATMS is to facilitate the safe movement of motorists and goods through roadway systems. This is achieved through the following:

- Collection of real-time traffic data

- Area-wide surveillance and detection systems
- Rapid response incident management strategies
- Coordination of all involved parties
- Provision of traffic information to motorists

Given the large number of traffic fatalities and injuries and the large amount of property damage that occurs on the roadways every year, improvements in safety (through incident management) are among the most important benefits derived from ATMS. Incident management resources reduce the duration and impact of incidents and increase the operating efficiency, safety, and mobility of highways by reducing the time it takes to detect an incident, implement an appropriate response, and clear the incident while managing the freeway traffic (McDade 1992).

Advanced Traveler Information Systems (ATIS) also play an important role in incident management and serve to make motorists aware of the hazards ahead. After receiving a warning via variable message signs (VMS) or highway advisory radio (HAR), motorists are expected to reduce their speeds, increase headways, or when possible, change their route in order to avoid the hazard ahead. Traveler information systems that warn drivers of incidents and blockages ahead will soften the propagating traffic shock wave caused by abrupt deceleration, according to Mobility 2000 (1990). Knipling et al. (1993) showed that traveler information can improve the driver-vehicle response to crash threats. Earlier driver awareness would lead to faster braking, thus enabling drivers to avoid secondary crashes.

Safety benefits of ITS technologies have also been reported in the literature. A study by Judycki and Robinson (1992) on the Traffic Information Center in Fairfax County, Virginia, revealed that since the incident management program began, a 40 percent reduction in the average incident duration has been realized. This change is a direct result of a more coordinated response through ATMS and faster clearance practices employed by the incident response teams.

The research on I-880 in California found that after the implementation of the freeway service patrol the average incident response time reduced by 37 percent, from 29 minutes to 18 minutes. The average clearance time of incidents and lane-blocking crashes also reduced significantly. Reducing emergency response times and saving lives were the two driving forces behind the development of TransGuide, San Antonio's smart highway system. The benefits of this new system have not yet been auantified, but it is anticipated that crash response will be reduced to just over two minutes (Gray (1995)). Raub (1997) also suggested that prompt incident response and clearance on roadways can be important in reducing the effect of incidents on traffic.

The Operation Timesaver (1996) report states that incident management programs reduce incident clearance times, thus reducing the number of secondary crashes and fatalities. Earlier research conducted by Mobility 2000 (1990) forecasted that the deployment of ITS would cause a 0.17 percent reduction in crash fatalities by 1995 and a 1.7 percent reduction by 2000, with figures improving to 18.9 percent by 2010. Unfortunately, the report does not state what measures should be used to realize those figures. The Operation TimeSaver report attributes a 15% - 50% decrease in the crash rate nationwide to Freeway Management Systems. These figures are supported by Preston (1996), who conducted crash research on Minnesota's highways over a three year period and concluded that ITS technologies could reduce rural freeway crashes by 25% and urban crashes by as much as 30%, with a total annual savings of $13 million.

2.4 Lessons from Literature Review

It is apparent from the literature review that studies on safety have not used a consistent set of variables for the models. As a result, it is very diicult to compare the results across studies. The reasons for this are as follows:

1. Some studies set out to prove or disprove the association of specific variables with crash rates. For example, a study of highways in Louisiana over a five-year period found that the crash rates increased on roadways with flat cross slopes, than those with steeper slopes (Dart and Mann, 1970). This variable is unique to the area, and would be inapplicable to other freeways.
2. Most of the safety studies are constrained by the availability of independent variables and use what is currently available.

Because of the nature of the data required for safety prediction, extensive (and reliable) data are very expensive to collect and may not be readily available. Some of the variables used by these studies for safety analysis include incident characteristics, environmental conditions, roadway and traffic characteristics, vehicle mix, and operational factors.

The survey also revealed that while much work has been done to quantify the safety benefits derived from the application of ITS technologies, there was little emphasis on combining the identification of specific crash scenarios and the application of various technologies. Therefore, there remains a need to identify the crash characteristics that have the greatest impact on secondary crashes and the ATMS technologies that would have the greatest positive impact on these characteristics.

3. DATA COLLECTION

3.1 The Hoosier Helper Incident Database

To develop models for the prediction of secondary crashes, an appropriate data set containing all the essential variables had to be selected. As mentioned in the literature review, the data set should ideally include explanatory variables such as weather conditions, volume of traffic time of occurrence (time-of-day and/or day-of-the week), location of the incident, percentage trucks, and most importantly for prediction models, the primary incident clearance times.

Hoosier Helper freeway service patrohnen maintain a daily activity log which documents all assists made. Appendix A of this report is a copy of the Hoosier Helper log sheet documenting the services offered by the service patrol. Completion of the log sheet includes the following details of the incident:

- Incident date
- Route number
- Direction
- Location post mile (mile marker)
- Start [Clearance] Time
- End [Clearance] Time
- Obstacle Type
- Obstacle Location

• Service Rendered

A total of 22,305 incidents were recorded by Hoosier Helper during the study period, September 1st 1991 to January 22nd, 1996. The distribution of the incidents by type is shown in Figure 3.1. The categories "Crashes" and "Abandoned/Nothing done" are self explanatory. The category "Overheating Vehicles" represents Hoosier Helper assists, which involved either providing water or dousing a fire. The "Other Minor Problems" category combines the remaining services and includes information, tire, fuel, or jump start. Incident assists made on the median (left) shoulder or the outside (right) shoulder were combined as "Shoulder" assists. AU assists made in the lanes or on the ramp were grouped as "In-lane" assists.

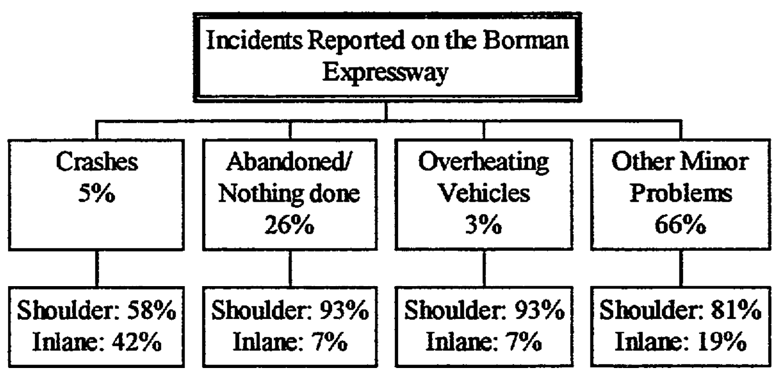


Figure 3.1 Incident Data for the Borman Expressway - (September 1st, 1991 to January 22nd, 1996)

Figure 3.1 shows that although crashes account for only 5% of the total number of incidents on the Borman Expressway, almost half of these crashes (42%) are lane-blocking, and thus more likely to be capacity reducing, causing traffic slow downs and resulting in secondary crashes. Conversely, 95 percent of all other occur on the shoulders (away from traffic flows) an average of 89 percent of the time. In light of this observation, a decision was made to develop the predictive models using only crash data since crashes on the Borman Expressway represent the greatest threat to roadway safety. This reduces the database to 1,13 1 crashes.

3.2 The Secondary Crash Database

3.2.1 Establishing a Basis for Secondary Crashes

In order to establish a relationship between a primary and a secondary crash event, the following question was addressed: At what distance from, and how long after, a crash occurred, is a subsequent crash considered as being related? A literature search revealed that Raub (1997) was the only source attempting to establish a space-time relationship between primary and secondary crashes. He suggested that a crash would affect traffic for the duration of the event plus 15 minutes. For this study, a crash that occurred before the clearance of a prior crash plus 15 minutes ($t_{CT,1st}$ + 15; where tCT 1st, is the clearance time of the primary crash) satisfied the temporal requirement of a secondary crash.

The two events were linked spatially using the mile marker information contained in the database. Literature was consulted and the current traffic conditions on the Borman examined in order to determine how far downstream the effect of the crash applies. According to Morales (1986), if the traffic flow approaching the incident is high (near capacity), the resulting back-up can grow at a rate of about 8.5 miles per hour – that is, after one hour the back-up will be approximately 8.5 miles long. During peak periods on the Box-man Expressway, the Hoosier Helper patrolmen have observed 6-mile queues develop in a mere 15 minutes after a crash occurrence (Shamo (1997)). In order to account for the off-peak periods on the Expressway, the distance of effect of a primary crash on the Borman was assumed to be three miles or less.

3.2.2 Identifying Secondary Crashes

The secondary crashes in the incident database were identified using a computer program written in QBASIC (Appendix B). The program reads the “service rendered’ column to identity a crash. When a crash has been identified, the program then searches the next 10 crashes to locate the crashes that fit the assumed spatial and temporal criteria for secondary crash identification. Using this method, 390 crashes were identified as secondary crashes and two new sub-categories were created for the primary crashes. A crash that was independent, neither causing nor resulting from another crash, was coded as a 0 primary crash. A primary crash linked to one or more secondary crashes was coded 1. Out of a total of 741 primary crashes, 484 were Code 0, while 257 were Code 1 primary crashes. The primary crash figures justify the use of crash incidents only. Table 3.1 shows that using the same secondary crash identification process for all 22,305 incident records, the number of secondary crashes increases to only 474. This supports the earlier assumption that crash incidents are more likely to result in secondary crashes.

Table 3.1 Borman Expressway Incident and Crash Database Comparison

	All Incidents		Crashes Only	
	Freq.	Percent	Freq.	Percent
Incidents w/o Secondary Crashes	21533	97%	484	43%
Incidents w/ Secondary Crashes	298	1%	257	23%
Secondary Crashes	474	2%	390	34%
Total	22305	100%	1131	100%

3.3 Primary Crash Characteristics

The original entries in the database were modified to create new variables. The date of the crash was used to create a variable for day-of-the week and for each of the four seasons (based on the solstices). The clearance time variable was created by finding the difference between the start and end clearance times. Dummy variables were created to represent the obstacle type and location, the season, and the day-of-the week. Table 3.2 describes all the variables used in the data set. With this new data set the focus now shifts to the explanatory variables associated with primary crashes that do and do not result in a secondary crash (Code 1 and Code 0 respectively).

An analysis of primary crashes revealed that the majority of the crashes involved cars. According to Table 3.3, cars accounted for 72 percent of all the primary crashes on the Borman. However, when considering only Code 1 crashes, car involvement increased to 76 percent. Table 3.4 shows that a little more than half of all crashes (50.2%) were assisted on the outside shoulder. This implies that most motorists are aware of the hazard they present to traffic and those that are able, move to the shoulders before the Hoosier Helper at-rives. The fewest primary crashes occurred during the summer and on weekends. Table 3.5 reveals that primary crash distribution by season marked the most erratic changes from one primary crash type to the next. While the largest number of Code 0 crashes occurred during the winter months, the winter was also the season that resulted in the fewest Code 1 crashes. This suggests that fewer secondary crashes tend to occur during the winter time. The figures for fall and spring did not change significantly from one crash type to the next.

Close analysis of the proportions of individual variable involvement in a Code 1 crash reveals that 37% of all semis involved in crashes results in a secondary crash. Likewise, 40% of all in-lane crashes are Code 1 crashes, as well as 57% of all weekday crashes. These proportions, as well as those for all the other variables, are shown in Table 3.8.

Table 3.9 contains primary crash clearance time statistics for all categories considered in the previous tables. The diierence between the mean of a Code 1 and a Code 0 primary crash ranged from 3.88 minutes to 19.89 minutes for each classification. In fact, the variation between the two average clearance times exceeded 10 minutes in nine of the 16 individual categories, and an overall comparison of Code 1 and Code 0 primary crash means yielded an 11.27 minute difference. The logistic regression analysis will attempt to determine whether clearance time and a host of other primary crash characteristics have an impact on the likelihood of secondary crash occurrence.

Table 3.2 Descriptors of the Variables in the Data Set for the Borman Expressway Database

Variable	Description
Clearance Time	Clearance time of the primary crash
Car	Cars (all sizes) and jeeps
Truck	Single Uunit trucks
Van	Mini vans
Semi	Combination trucks
Ramp	On-off ramps
Median	Median (left) shoulder
Shoulder	Outside (right) shoulder
Left Lane	Left (overtaking) lane
Center Lane	Center lane
Right Lane	Bight lane
Weekday	Monday to Friday
Weekend	Saturday and Sunday
Fall	Fall solstice
Winter	Winter solstice
Spring	Spring solstice
Summer	Summer solstice

Table 3.3 Borman Expressway Primary Crash Distribution by Vehicle Type

	Primary Crash Code					
	0		1		0 and l	
Vehicle Type	Freq.	Pct. of All Types	Freq.	Pct. of All Types	Freq.	Pet. of All Types
Car	330	69.8%	191	76.1%	521	72.0%
Van	26	5.5%	2	0.8%	28	3.9%
Truck	43	9.1%	15	6.0%	58	8.0%
Semi	74	15.6%	43	17.1%	117	16.2%
All Types	473	100.0%	251	100.0%	724	100.0%

Table 3.4 Borman Expressway Primary Crash Distribution by Vehicle Location

	Primary Crash Code					
	0		1		O and 1	
Vehicle Location	Freq.	Pct. of Location	Freq.	Pct. of Location	Freq.	Pct. of Location
Median Shoulder	74	15.8%	30	12.0%	104	14.5%
Left Lane	47	10.0%	31	12.4%	78	10.9%
Center Lane	33	7.1%	23	9.2%	56	7.8%
Right Lane	43	9.2%	27	10.8%	70	9.8%
Right Shoulder	237	50.6%	123	49.4%	360	50.2%
Ramp	34	7.3%	15	6.0%	49	6.8%
All Locations	468	100.0%	249	100.0%	717	100.0%
Total Shoulder	311	66.5%	153	61.4%	464	64.7%
In-Lane	123	26.3%	81	32.5%	204	28.5%
Ramp	34	7.3%	15	6.0%	49	6.8%
All Locations	468	100.0%	249	100.0%	717	100.0%

Table 3.5 Borman Expressway Primary Crash Distribution by Season

	Primary Crash Code					
	0		1		0 and 1	
Season	Freq.	Pct. of Season	Freq.	Pct. of Season	Freq.	Pct. of Season
Fall	136	28.1%	74	28.8%	210	28.3%
Winter	142	29.3%	59	23.0%	201	27.1%
Spring	116	24.0%	63	24.5%	179	24.2%
Summer	90	18.6%	61	23.7%	151	20.4%
All Seasons	484	100.0%	257	100.0%	741	100.0%

Table 3.6 Borman Expressway Primary Crash Distribution by Day-of-the Week

Day-of-the Week	Primary Crash Code 0		1		0 and 1	
	Freq.	Pct. of Week	Freq.	Pct. of Week	Freq.	Pct. of Week
Weekday	348	71.9%	200	77.8%	548	74.0%
Weekend	136	28.1%	57	22.2%	193	26.0%
Entire Week	484	100.0%	257	100.0%	741	100.0%

Table 3.7 Analysis of Secondary Crashes by Vehicle Type
for the Borman Expressway

Vehicle Type	Secondary Crash Freq.	Secondary Crash Percent
Car	142	36.4%
Van	37	9.5%
Truck	69	17.7%
Semi	135	34.6%
Other	7	1.8%
Vehicles	390	100.0%

Table 3.8 Primary Crash Involvement by Explanatory Variable

Explanatory Variables	Primary Crashes			
	Code 0		Code 1	
	Freq.	Percent	Freq.	Percent
Car	330	63%	191	37%
Van	26	93%	2	7%
Truck	43	74%	15	26%
Semi	74	63%	43	37%
Median	74	71%	30	29%
Right Shoulder	237	66%	123	34%
Left Lane	47	60%	31	40%
Center Lane	33	59%	23	41%
Right Lane	43	61%	27	39%
Ramp	34	69%	15	31%
Total Shoulder	311	67%	153	33%
In-Lane	123	60%	81	40%
Fall	136	65%	74	35%
Winter	142	71%	59	29%
Spring	116	65%	63	35%
Summer	90	60%	61	40%
Weekday	348	64%	200	36%
Weekend	136	70%	57	30%

Table 3.9 Borman Expressway Primary Crash Clearance Times

Explanatory Variable	Primary Crash Code					
	0		1		0 and 1	
	Mean	STD	**Mean**	**STD**	Mean	STD
Car	22.69	17.68	**32.66**	**21.85**	26.35	19.88
Van	18.12	16.03	22.00	11.31	18.39	15.61
Truck	19.58	14.78	34.93	23.05	23.55	18.37
Semi	26.82	21.63	39.53	34.85	31.50	27.79
Median	21.42	15.17	31.10	20.28	24.21	17.39
Bight Shoulder	20.78	17.38	29.76	21.53	23.84	19.35
Left Lane	23.94	17.72	30.16	15.86	26.41	17.17
Center Lane	26.36	22.78	42.96	21.98	33.18	23.73
Right Lane	27.00	19.54	46.89	39.65	34.67	30.33
Ramp	26.88	18.32	37.53	19.24	30.14	19.06
Total Shoulder	20.93	16.86	30.02	21.30	23.93	18.91
In-Lane	25.66	19.69	39.37	28.18	31.10	24.3 1
Fall	23.15	18.52	38.23	28.90	28.46	23.78
Winter	24.80	19.68	34.81	27.95	27.74	22.82
Spring	19.93	15.09	29.06	16.50	23.15	16.15
Summer	22.40	17.91	33.13	20.77	26.74	19.77
Weekday	23.00	18.37	33.87	22.94	26.97	20.80
Weekend	22.01	17.23	34.40	29.06	25.67	22.07
Overall	22.72	18.04	33.991	24.37	27.001	21.00

4. MODEL DEVELOPMENT AND ESTIMATION

4. 1 Model Develonment

4.1. 1 The Logistic Regression Model

Regression methods are an integral part of any data analysis concerned with describing a response (dependent) variable as a function of one or more explanatory variables. The response variable merits special attention when determining the appropriate regression method.

In the usual regression framework, the dependent variable is assumed to be continuous. In addition, the conditional mean (the mean value of the outcome variable, given the values of the independent variables) is expressed as E(Ylx'), where Y represents the outcome variable and x' = (x1,x2, . . .,xp, denotes the values of p independent variables. In linear regression this mean is expressed as an equation linear in the parameters. The mean can be written as follows:

$$E(Y|x') = P_O + B_1x_1 + B_2x_2 + .B_px_p$$

This equation implies that it is possible for E(Y|x') to take on any ***value as x'*** changes.

The above framework is not appropriate when the response variable is discrete rather than continuous. In this situation, the conditional mean must be a value that lies between 0 and 1(i.e., 0<=E(Y|x') <=1 In this research, the dependent variable is binary (O/l), since it takes the value of 0 for primary crashes that are not followed by a secondary crash, and 1 for primary crashes followed by a secondary crash. As a result we wish to determine the **probability** that a secondary crash will occur, given the descriptors of the primary crash.

Since the dependent variable Y can take on two values, 0 and 1, the probability distribution of Y can be described by letting $P_i = \text{Prob}(Y=1)$. In order to ensure that $0 \leq E(Y|\mathbf{x}') \leq 1$, the linear model is transformed using the *cumulative logistic probability function, F*, so that predictions lie in the (0/1) interval for all **x**. A cumulative probability function is defined as having as its value the probability that an observed value of a variable **x** (for every **x**) will be less than or equal to a particular **x**. The range of the cumulative probability function is the (0/1) interval, since all probabilities lie between 0 and 1 (Pindyck and Rubinfeld 1991).

The logistic model, which is based on the cumulative logistic probability function, can be specified as follows:

$$P_i = F(Z_i) = F(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_p x_p)$$

$$= \frac{1}{1+e^{-Z_i}} = \frac{1}{1+e^{-(\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_p x_p)}} \tag{4.1}$$

where with β represents the coefficient of the explanatory variable x.

Multiplying both sides of the equation by $1 + e^{-Z_i}$ we get:

$$e^{-Z_i} = \frac{1}{P_i} - 1 = \frac{1-P_i}{P_i} \tag{4.2}$$

Inverting the equations gives:

$$e^{Z_i} = \frac{P_i}{1-P_i} \tag{4.3}$$

By taking the logarithm on both sides, this equation becomes:

$$Z_i = \log\left(\frac{P_i}{1-P_i}\right) \tag{4.4}$$

Therefore, it follows from equations (4.1) and (4.4) that:

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_p x_p \tag{4.5}$$

The odds ratio of each explanatory variable, **x**, is a measure of association and is used to interpret the estimated coefficients. The odds ratio approximates how much more likely it is for the outcome to be present, given the presence of the independent variable in the logistic regression. Therefore, the logistic model transforms the problem of predicting probabilities within a (0/1) range to the problem of predicting the odds of an event occurring within the range.

4.1.2 The Independent Variables

In order to establish a link between a primary crash and the likelihood of secondary crash occurrence, a series of explanatory variables were considered for possible inclusion in the logistic regression model. The variables depict primary crash characteristics. In essence, the study seeks to determine what primary crash characteristics increase the likelihood of secondary crash occurrence. A strong possibility exists that the following primary crash characteristics can influence the likelihood of secondary crash occurrence:

- Clearance Time (CLT): It can be expected that the likelihood of a secondary crash, caused by a driver upstream of a primary crash, increases as primary crash clearance time increases (the longer a disabled vehicle remains on the roadway, the higher the likelihood that a secondary crash will occur). Clearance time was the only continuous variable specified in the model.
- Vehicle Type: The vehicle type may influence the clearance time of the primary crash; larger vehicles (e.g. single unit and semi trucks) require a longer clearance time. This variable may also influence a driver's abiity to detect a crash downstream, thus placing the driver at risk because of inadequate sight distance or impatient behavior resulting from congestion delays (vehicles considered were cars (CAR), trucks (TRK), semis (SEMI), vans (VAN), and buses BUS)).
- Vehicle Location: This stands as an indirect measure (proxy) of the prevailing speed of traffic (vehicles move faster on the left and center lanes as opposed to the ramp and the right lane). Further, operating speed influences stop times for avoiding involvement in a secondary crash (locations considered: left lane (LL), right lane (RL) center lane (CL), median shoulder (MS), right shoulder (RS), and ramp (RMP)).
- Season: Prevailing weather conditions affect the driving conditions (traction and visibility) which, in turn may influence the behavior of motorists and the likelihood of

occurrence of a secondary crash (seasons: winter (WNT), spring (SPR), summer (SMR), and fall (FALL)).

- Day of the Week: This measure acts as a proxy for the traffic volumes, vehicle mix, and possibly driver attitudes (days: weekdays (WKD), and weekends (WND)).

4.2 Model Estimation

4.2.1 Estimating the Variables

Starting with the initial set of 18 explanatory variables, the next step was the selection of those variables that result in the "'best" model to predict secondary crashes. Some variables were selected a priori based on the crash data and the conditions on the Borman Expressway. CLT was included in the first trial of the model because previous studies have implied that the impact of a primary crash on traffic conditions is related to its duration. (Judycki et al (1992), Korpal (1992), Gray (1995)). TRK and SEMI were then added because of the unusually high proportion (higher than the national average) of heavy vehicles on the Expressway. Inspection of Table 3.3 suggested the inclusion of CAR, but the exclusion of VAN, which had no apparent effect on secondary crashes. WKD, shown in Table 3.6, was included by the same token.

Table 3.5 suggests that careful attention be paid to winter. It is unusual that a season with the highest proportion of primary crashes without a secondary crash (Code 0), would have the lowest proportion of primary crashes with a secondary crash (Code 1). This merits further investigation, and therefore WNT was added. This observation also led to the development of a "season-specific" model (Model 2) to further explore the significance of the seasons. CLT was combined with WNT in Model 2, to become CLTWNT, or the clearance time during winter. CLTALL represents the clearance time for all of the other seasons combined.

The remaining variables were then selected based on their p-values and/or their interaction with the other variables. Any variable with a p-value < 0.25 was considered a candidate for the models (Bendel and Afifi 1977, Mickey and Greenland 1989, Hosmer and Lemeshow 1989). The only exception was the variable TRK, which had a high p-value, but was thought to be important for comparative purposes (with the variable SEMI). This method served to eliminate LL, CL, RL, and RS, while identifying RMP and MS for possible inclusion.

4.2.2 Testing the Models

A series of likelihood ratio tests (LRT), as well as the Akaike's Information Criterion (AIC) (Green 1993) were used to develop the two models. The AIC was used to compare the models as it is generally suggested that a model with a lower AIC value is "better" than a model with a higher AIC value.

After preliminary models were identified, we attempted to assess their goodness-of-fit. That is, an appropriate expanded model was tested to determine whether the contribution of an additional variable (or the deletion of an existing variable) is statistically significant. For the type of non-linear models used in this research, the measure of goodness-of-fit most commonly employed is p2 (rho-squared). Although this is a more informal goodness-of-fit index, it is analogous to the R2 from regression. It is defined as

$1-(L(B) / L((o))$ and measures the fraction of the initial log likelihood value explained by the model.

The estimation results are shown in Table 4.1. The coefficients for the variables are mostly as expected: increased clearance time for the primary crash leads to higher likelihood of secondary crash occurrence, similar to most hypotheses in the literature (Judycki et al. 1992; Korpal 1992). As noted earlier, two different models were developed. They can be written as follows:

Model 1:

$$\log\left(\frac{P_i}{1-P_i}\right) = -2.33+0.03CLT+0.97CAR+0.44TRK+0.76SEMI$$

$$-0.40WNT+0.35WKD-0.26RMPMS \qquad (4.6)$$

Model 2:

$$\log\left(\frac{P_i}{1-P_i}\right) = -2.45+0.02CLTWNT+0.03CLTALL+0.96CAR+0.42TRK$$

$$+0.73SEMI+0.35WKD-0.25RMPMS \qquad (4.7)$$

Model 1 includes clearance time as a single independent variable. Model 2 includes clearance time specific to winter and to all other seasons combined. To develop Model 2, we initially developed a model where clearance time was specific to each

Table 4.1 Estimation Results for Logistic Regression Models

Explanatory Variable	Model 1 Coefficient Estimate	Model 1 t-ratio	Model 1 odds ratio	Model 2 Coefficient Estimate	Model 2 t-ratio	Model 2 odds ratio
Constant	-2.32	5.3		-2.44	5.61	
Clearance Time	0.027	6.72	1.028			
Clearance Time (winter specific)				0.017	3.26	1.018
Clearance Tie (spring, summer, and fall specific)				0.03 1	6.69	1.032
Car	0.966	2.36	2.62	0.964	2.34	2.62
Truck	0.442	0.76	1.55	0.415	0.67	1.51
Semi	0.762	1.71	2.14	0.73 1	1.67	2.07
Winter	-0.402	2.11	0.66			
Weekday	0.346	1.81	1.41	0.353	1.83	1.42
Ramp/Median	-0.264	1.32	0.76	-0.248	1.21	0.78
Summary Statistics						
No. of Observations	741			741		
L(0)	956.57			956.57		
L(B)	580.34			558.22		
Rho-squared	0.39			0.41		

season. Then, with a series of LRT tests, we could not reject the null hypothesis of equality of the coefficients of the clearance times specific to all seasons except winter.

4.2.3 Validating the Models

The value of p2 obtained from these models can be characterized as good for both Models 1 and 2 (p2 = 0.39, 0.41 respectively) (Ben-Akiva and Lerman 1985). To expand the examination of goodness of fit, a table depicting the number of crashes for which the model predicted the "code" correctly is presented in Table 4.2. This table presents the actual (observed) and the predicted (from Model 2) number of crashes for each crash code. We note that there were 484 Code 0 crashes, for which the model predicted correctly 401, or 82.8%. Similarly, there were 257 Code 1 crashes, for which the model predicted correctly 185, or 71.9%. The actual vs. predicted results from Model 1 are very similar (within 2%) to those obtained from Model 2. Overall, Model 2 correctly predicted the crash code for approximately 78% of the crashes. While the results are quite satisfactory, it is hoped and expected that once larger data sets become available the results will improve.

4.2.4 Interpreting the Models

The results presented thus far can be useful in investigating the direction of effect of those factors that contribute to secondary crash occurrence, but we also wish to examine the magnitude of these effects. After fitting the model, the emphasis shifts from the computation and assessment of the significance of estimated coefficients to the interpretation of their values. The interpretation of a fitted model enables us to draw practical

Table 4.2 Actual and Predicted Crashes by Crash Code

Actual		Predicted (no. of observations)		% correctly predicted
Crash Code	No. of Observations	0	1	
0	484	401	83	82.8
1	257	72	185	71.9

inferences from the estimated coefficients of the model. It involves determining the functional relationship between the dependent variable and the independent variable.

The odds ratio (presented in Table 4.1 for each coefficient of each model) is used to measure the strength of an association between an independent variable and the response variable (Green 1993).[1] The odds ratio (OR) ranges from 0 to infinity and approximates how much more likely (or unlikely) it is for an outcome to be present given the existence of the independent variable. When OR is greater than 1, this indicates that primary crashes are more likely to be followed by a secondary crash. When OR is less than 1, this indicates that primary crashes are less likely to be followed by a secondary crash.

For example, the odds ratio of CLT from Model 1 is 1.028. This means that in the first minute of clearance time, the likelihood of a primary crash being followed by a secondary crash increases by 1.028, or ($e^{0.027*10}$) If the clearance time of the primary crash increases to 10 minutes, the likelihood of a secondary crash increases by 28% to 1.31 ($e^{0.027*10}$). Further, if clearance time increases from 10 minutes to 20 minutes, the secondary crash likelihood increases an additional 3 1% to 1.72. The increase in the secondary crash likelihood with an increase in clearance time is depicted in Figure 4.1. The three graphs represent the clearance time odds ratios in the two models.

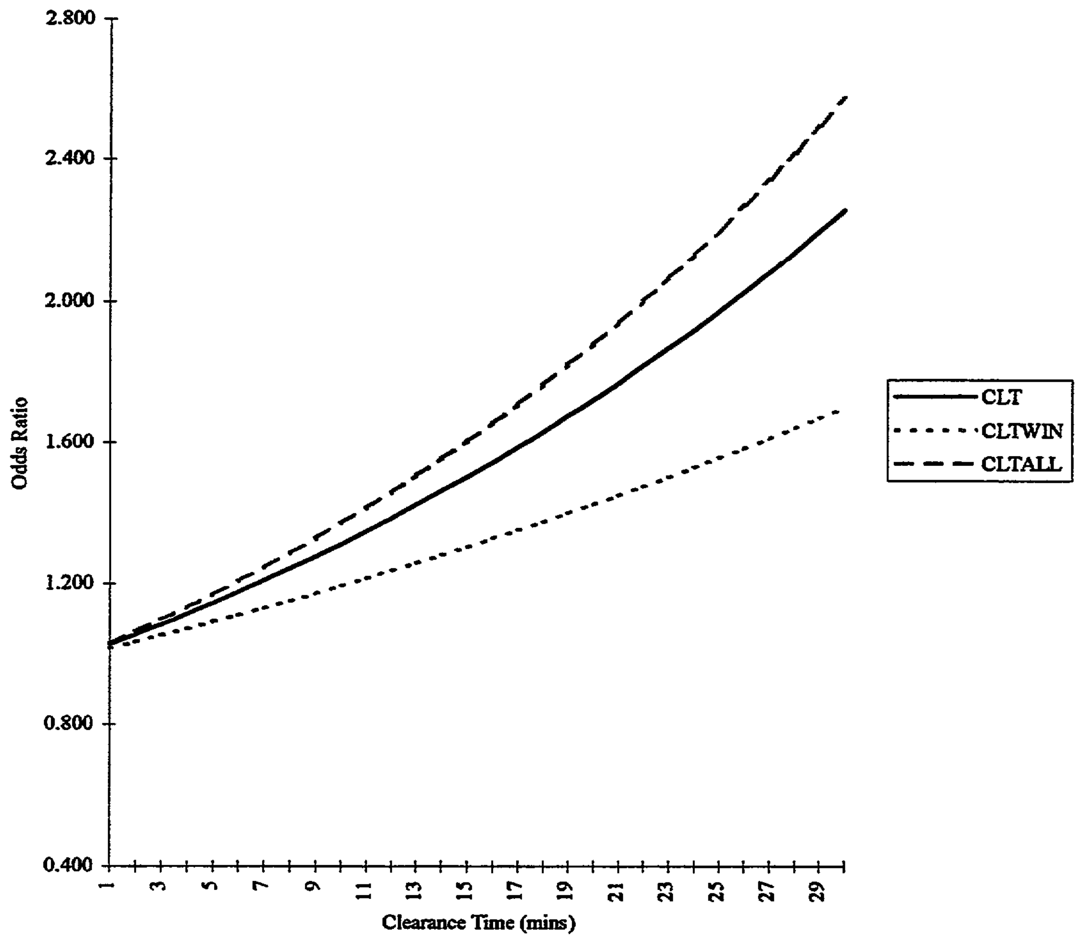
As shown in Table 4.2, the OR for clearance time of Model 2 seems to suggest that an increase in clearance time for the primary crash increases the likelihood of a

1The odds ratio for a variable x is derived by finding the exponential of its coefficient (B).

secondary crash less in the winter than in other seasons. This might seem counter-intuitive at first, but it is reasonable to expect that drivers are inherently more careful over winter months and drive at lower speeds, thus reducing the probability of a secondary crash (Brown and Bass 1997).

The ORs for the other variables are consistent for both models. For example, the OR for the variable CAR is 2.62 for Model 1 and Model 2. This indicates that the predictive powers of the other variables in the Model 2 are not seriously affected by seasonal effects of clearance time. Our models suggest that primary crashes involving cars and semis have an increased likelihood of being associated with a secondary crash, relative to other types of vehicles. Crashes during weekdays also have a higher likelihood of being followed by a secondary crash, probably due to the higher traffic volumes during the weekdays.

The models also reveal that crashes occurring on ramps and medians have a lower probability of being associated with a secondary crash. The lower volumes and speeds on ramps account for this effect. Motorists have time to slow down to avoid an incident. In addition, the queues building on ramps are also less likely to affect the mainstream flows than queues building on the freeway. Motorists are also less likely to use the median shoulder in the event of an incident thus accounting for its effect in the model. Finally, the one additional coefficient of Model 1 (winter) suggests that primary crashes that occur during the winter have a lower likelihood of being followed by a secondary crash.



CLT- Clearance Time (Model 1)

CLTWIN - Clearance time in winter (Model 2)

CLTALL - Clearance time in fall, spring, and summer (Model 2)

Figure 4.1 Change in Crash Likelihood with respect to Clearance Time

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Safety Analysis Summary

Logistic regression analysis of crash data for the Borman Expressway was used to identify the primary crash descriptors that influence secondary crash occurrence and quantify their impacts. Two models were developed to predict the likelihood of a primary crash being followed by a secondary crash, using seven of the 18 primary crash descriptors identified in the database.

Four of the seven statistically significant primary crash descriptors were found to increase the likelihood of secondary crash occurrence, clearance time of the primary crash, and vehicle types (car, truck and semi). Three statistically significant descriptors were found which decreased the chance of a secondary crash: winter, and two lateral locations (ramp and median shoulder).

The odds ratios for each of the explanatory variables allow us to quantify the impact of each descriptor and draw practical inferences from the estimated coefficients. The identification of those factors that contribute to secondary crash occurrence can assist in evaluating existing or proposed ITS technologies on the Borman to determine their impact on roadway safety.

5.2 Safety Benefits of ITS

5.2.1 Clearance Time

As noted in the previous section, the likelihood of a secondary crash increases with an increase in primary crash clearance time. Figure 4.1 shows that this increase in secondary crash likelihood increases exponentially with clearance time. Further, Table 3.9 shows that the average clearance time for heavy vehicles involved in primary crashes is much higher than for cars. Any action that can reduce clearance times would therefore improve safety. For example, the addition of one or more tow trucks to the Hoosier Helper fleet can be investigated. Under existing conditions, the patrolmen remove lane-blocking vehicles that are still mobile upon arrival at the crash scene. However, for more severe crashes or crashes involving larger vehicles (trucks and semis), the assistance of a tow truck is needed and removal is delayed until it arrives. This arrival may be further delayed by the queues resulting from the crash. If tow trucks are already at the disposal of the Hoosier Helper they can expeditiously remove all crash vehicles upon arrival at the scene.

The emergency medical service (EMS) response time to crashes can also delay the clearance of crash vehicles when injuries are involved. In severe crash cases when the patrolmen are reluctant to move motorists for fear of further injuries, the timely dispatch of emergency crews is crucial. In the past, problems have arisen when EMS crews fi-om the wrong jurisdiction were notified, or the right EMS crews were sent to the wrong traffic direction. This human error will be eliminated with the implementation of a Geographic Positioning System (GPS), to be used in conjunction with an expert system for reporting incidents. When reporting an incident, patrolmen will be prompted to answer several standard questions, such as the mile post location of the crash, the lateral location of the crash, the number of vehicles involved, the direction, the severity, and the estimated clearance time. When this information is combined with the GPS, the appropriate EMS team would immediately be contacted (depending on the severity of the crash), and dispatched to the correct location

5.2.2 Detection Time

The clearance time of the primary crash can be reduced by minimizing crash detection time. Currently, there is no mechanism to determine and record the incident detection time, and no records exist for the detection time for each incident. An effort should be made to identity the actual occurrence time of an incident. This would allow for the evaluation of the detection and response performance of the Hoosier Helper.

Future improvements to ITS technologies on the Borman Expressway include the increase in the number of closed-circuit television (CCTV) cameras from a total of two to one camera per ramp in each direction. This arrangement would effectively cover most of the 16 miles of the Expressway because most of the proximity of the ramps with each other. The largest distance between ramps of just over two miles can be accommodated by the placement of an additional camera in the middle of that link. Incident detection times will improve because the service vehicles will be equipped with CCTV that monitor the transmission of the cameras. Cameras will also be placed on the service vehicles in the advent of a severe crash that does not allow the patrolmen to report the incident. Another crew (m a traffic management center or in a vehicle) would then be able to use the images provided by the in-vehicle camera to file an incident report.

The crash detection time can further be improved with the implementation of a cellular phone service that directly connects motorists to the service fleets and/or a traffic management center (TMC). In anticipation of the large volume of calls that would probably flood the incident detection hot line, a link to a TMC can be considered. A TMC would relieve the patrolmen of the need to decipher the phone calls, thus enabling them to focus on incident location and removal.

5.2.3 Season

While the winter months were found to reduce the likelihood of a secondary crash, it should be carefully noted that this season also has the highest number of independent primary crashes. The fact that a large number of primary crashes are occurring with a correspondingly low number of secondary crashes can lead us to conclude that secondary crashes are infrequent because of the lower speeds and larger headways typical of this time of year. Therefore, although more crashes are occurring because of the climatic conditions, fewer motorists are managing to avoid these crashes. This can be applied to other seasons. Motorists must be informed and constantly reminded that shorter headways and greater speeds lead to higher risks. Motorists can be reminded with VMS or sign boards, although it is doubtful that this would be effective. Perhaps in the future, in-vehicle devices can be used to warn drivers of dangerous headways.

5.2.4 Motorists Awareness

Keeping drivers informed of crashes in their forward path should reduce the likelihood of secondary crashes because of changes in driver attitudes, and the opportunity for motorists to divert around a primary crash. Driver information is possible with the use of Advanced Traveler Information Systems (ATIS), a component of ITS. At present, the Hoosier Helper patrolmen radio information to a command center that reports to the radios and updates the information on VMS. However, an expert system in place, the patrolmen will be able to create and send HAR and VMS messages from the incident site, using an in-vehicle computer and transmitter and the standard incident report. This information will be used to update the VMS and HAR in real time, thus ensuring a quicker response to incident conditions from motorists.

5.3 Conclusions

In the present study logistic regression models were developed to determine the primary crash characteristics that influenced secondary crash occurrence, so that the possible impact of ITS technologies on safety could be analyzed. Two models utilizing seven primary crash descriptors were developed. These models were tested using the crash database and were found to correctly predict the crashes more than 75% of the time. Although satisfactory, it is expected that the results will improve with larger data sets. It should be noted that the methodology used for this database can be applied to any database to predict secondary crash occurrence.

The study showed that safety conditions on the Borman Expressway could best be improved with the expeditious clearance of all primary crashes. Clearance would be aided with an upgrade of the current service patrol fleet to include a tow truck, an expert system for reporting incidents, a GPS system to automatically dispatch the correct EMS service, and a television and camera. An upgrade of the existing ATIS technologies is also essential in secondary crash avoidance. More frequent VMS signs and a more efficient updating method for the VMS and HAR messages would lead to quicker motorists response, thus reducing the chance of a secondary crash. These examples demonstrate how road safety and the application of ITS technologies can be improved using the methodology presented in this study.

5.4 Directions for Future Research

While this research focuses on determining the primary crash characteristics that influence secondary crashes and the ITS technologies which can be employed to possibly reduce secondary crash occurrence, further study is needed to model secondary crash occurrence after the suggested implementations, to quantity the benefits. The GCM Plan anticipates that incident response time would be reduced by 40%, and the number of crashes by 38%, with the implementation of ITS. These figures are based on benefits derived on other freeways in the U.S. and Canada, but cannot be verified until crashes are modeled using the ITS technologies suggested above.

In addition, it should be noted that the models developed in this research were restrained by the initial assumptions used to link the primary incident and secondary crash events. The random nature of primary incidents makes it difficult to model secondary crashes, however an attempt should be made to model secondary crash occurrence based on freeway and traffic characteristics.

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APPENDIX A: HOOSIER HELPER LOG SHEET

APPENDIX A: HOOSIER HELPER LOG SHEET

Hoosier Helpers Daily Activity Log

Hoosier Helper ________________
Badge Number ________________
Unit ______#

Date ________
Ending Mileage ________
Beginning Mileage ________
Total Mileage ________
Unleaded Fuel ________ gal.
Diesel Fuel ________ gal.
Antifreeze ________ gal.
low30 oil ________ qt.

Start Time	Road	Direction	Mile Marker	State	License Plate #	Obstacle Type	Obstacle Location	Services Rendered	Finish Time	Comments

Obstacle Type
S=Semi
T=Truck
C=Car
D=Debris
P=Pedestrian
R=RV
B=Bus
M = Motorcycle
v=van

Obstacle Location
M = Median Shoulder
L=Left Lane
C=Center Lane
R=Right Lane
S = Outside Shoulder
x=Ramp

Services Rendered
I = Information
G=Gas
T=Tire
J=JumpStart
W = Wrecker
N = Nothing Done
x=Crash
c=Called Other
A = Abandoned Vehicle
M=MinorRepair
F=Fire
H=Water
R = Remove from Roadway
S = Woke Sleeping Motorist
E=Escort
z = Other(write Comments)

APPENDIX B: PROGRAM TO IDENTIFY SECONDARY CRASHES

APPENDIX B: PROGRAM TO IDENTIFY SECONDARY CRASHES

The following program is written in the QBASIC programming language.

```
1000    THIS PROGRAM LOCATES SECONDARY CRASHES FROM INCIDENT DATA
1005    '*********************************************
1020    DlM dat$(l5), stat$(l5), road(15), dir$(l5), mile(15)
1030    DIM otype$(15) oloc$(15), service$(15), finish$(15)
2000    OPEN "c:\project\inl.csv" FOR INPUT ACCESS READ AS #l
2010    OPEN "c:\project\outl.csv" FOR OUTPUT ACCESS WRITE AS #2
2020    OPEN "c:\project\in2.csv" FOR INPUT ACCESS READ AS #3
3000    FOR record = 0 TO 10
3010    INPUT #l, dat$(record), start$(record), road(record), dir$(record), mile(record), otype$(record),
        oloc$(record), service$(record), finish$(record)
3005    GOSUB 8000
3020    NEXT record
4000    WRITE #2, "DATE", "START TIME", "ROAD", "DIRECTION", "MILE", "OBJECT TYPE",
        "OBJECT LOC.", "SERVICE", "FINISH TIME", "MILE DIF.", "TIME DlF."
4020    WRITE #2, dat$(0), start$(0), road(0), dir$(0 ), mile(0), type$(0),oloc$(0), services$(0), finish$(0)
5000    FOR i = 1 TO 10
5020    'THE NEXT "IF" CHECKS' "SERVICE RENDERED" TO FIND ALL CRASHES.
5030    IF INATR9service$(i) "X") = 0 AND INSTR(service$(i), " W" = 0 THEN GOTO 5170
5050    'THE NEXT "IF" CHECKS "MILE MARKER" TO DETERMINE IF CRASHES ARE WITHIN
5060    '3 MILES OF EACH OTHER
5070    IF mile(0) - mile(i) > 3 OR mile(0) - mile(i) < -3 THEN GOTO 5170
5090    MILEIF = mile(0) - mile(i): IF miledif < 0 THEN miledif = -1 * miledif
5100    "THE NEXT IF CHECKS TO DETERMINE E IF CRASHES OCCUR ON THE SAME ROAD.
5110    IF road(0)<> road(i) THEN GOTO 5170
5120    'THE NEXT "IF" CHECKS TO DETERMINE IF THE "FINISH TIME" OF THE FIRST
5 130   'INCIDENT OCCURS BEFORE THE "START TIME" OF THE ITH CRASH
5140    GOTO 7000: TO CONVERT TIMES, CHECK TIME CORRELATION AND CALC. TIMEDIF
5 150   IF notover = I THEN GOTO 5170
5 160   WRITE #2, dat$(i), start$(i), road(i), dir$(i), mile(i), otype$(i), oloc$(i), servic$(i), finish$(i),
        miledif, timedif
5170    NEXT1
5180    WRITE #2,
6000    FOR i = l TO l0
6010    k = i -1
6020    dat$(k) = dat$(i): start$(k) = start$(i): road(k) = road(i): dir$(k) = dir$(i)
6030    mile(k) = mile(i): otype$(k) = otype$(i): oloc$(k) = oloc$(i):
```

```
6035   service$(k) = service$(i): finish$(k) = finish$(I)
6040   NEXT 1
6050   IF EOF(1) = 0 THEN
6060   INPUT #l, dat$(l 0), star$(l0), mad(l0), dir$(l0), mile(l0), otype$(l0), olcc$(l0), service$(l0), finish$(10)
6070   ELSE INPUT #3, dat$(10) start$(10). rpad(10), dirS(10), mile(l0), olype$(l0), olcc$(l0), service$(10)
       finish${ 10)
6080   lines = lines + 1
6090   IF lines = 11 THEN GOTO 9000
6100   END IF
6004   record = 10
6005   GOSUB 8000
6110   GOT0 4020
7000   '*********************************************************************
7002   TIME DIFFERENCE SUBROUTINE
7004   "*********************************************************************
7010   'The next lines calculate the difference in the "hours"
7070   cloc0 = INSTR(start$(0) ": "
7130   cloci = INSTR(start$(i), ":")
7210   hourf 0 $ = LEFT$(finish$(0) cloc0 - 1)
7220   hournuf0 = ASC(hourf0$) - 48
7230   IF LEN(hourf0$) = 2 THEN
7240   rightf0$ = FIGHT$(hourf0$) 1)
7245    IF LEFT$(hourf0$, 1) = "1" THEN numf0 = 10 ELSE numf0 = 20
7250   houenuf0 = numf0 + ASC(rightf0$) - 48
7260   END IF
7270   minf0$ = RIGHT$(finish$(0), 2)
7280   minnumf0 = (ASC(rninf0$) - 48) * 10 + (ASC(RIGHT$(minf0$, 1)) - 48)
7290   timminf0 = 60 * hournuf0 + minnumf0
7300   'The next lines convert start$(0) and start$(i) to minutes.
73 10  hour0$ = LEFT$(start$( 0) cloc0 - 1): houri$ = LEFT$(start$(i), cloci - 1)
7320   hournum0 = ASC( hour0$) - 48
7325   hournumi = ASC(houri$) - 48
7330   IF LEN(hour0$) = 2 THEN
7335   right0$ = RIGHT$ (hour0$, 1)
7340   IF LEFT$(hour0$, 1) = "1"  THEN num0 = 10 ELSE num0 = 20
7350   hournum0 = num0 + ASC(right0$) - 48
7360   END IF
7370   IF LEN(houri$) = 2 THEN
7380   righti$ = RIGHT$(houri$, 1)
7385   IF LEFT$(houri$, 1) = "1" THEN numi = 10 ELSE numi = 20
7390   houmumi = numi + ASC(righti$) - 48
7400   END IF
7410   mini$ = RIGHT$(start$(i), 2): min0$ = RIGHT$(start$(0), 2)
7420   minnumi = (ASC(mini$) - 48) * 10 + (ASC(RIGHT$(mini$, 1)) - 48)
7430   minnum0 = (ASC(min0$) - 48) * 10 + (ASC(RIGHTS(min0$ 1)) - 48)
7440   timmin0 = 60 * hournum0 + minnum0 timmini = 60 * hournumi + minnumi
7450   IF dat$(0) = dat$(0) THEN 7460 timedif= timmini - timmin0
7470   ELSE timedif= timini + 24 * 60 - timmin0
7480   END IF
```

```
7490  ‘The next lines check time correlation betweenfinish$(0) and start$(i)
7500  IF dat$(0) = dat$(i) THEN
7510  IF timminf0 < timmini THEN notover = 1 ELSE notover = 0
7520  ELSE timmini=timmini+24*60
7530  IF timminf0 < timmini THEN notover = 1 ELSE notover = 0
7560  END IF
7570  timmin0= 0: timmini = 0: minnumi = 0: minnum0 = 0: hournum0 = 0:hournumi = 0
7580  numi=0: num0=0: numf0=0: hournuf0=0: hournuf0=0:timinf0=0:
7590  mini$=": houri0$=":houri$=": hourf0$=": hourf0=": minf0$ = ": min0$ = ”
7600  GOTO 5150
8000
8010  REM
8020  cloc = INSTR(star$(record), “:“)
8030  IF cloc = 0 THEN
8040  IF LEN(start$(record)) = 3 THEN lft = 1 ELSE lft = 2
8050  start$(record) = LEFT$(start$(record), lft) + “:” + RIGHT$(start$(record), 2)
8060  END IF
8130  clocf = INSTR(finish$(record), “:“)
8140  IF clocf=0 THEN
8150  IF LEN(finish$(record)) = 3 THEN lft = 1 ELSE lft = 2
8160  finish$(record) = LEFT$(finish$(record), lft) + “:” + RIGHT$(finish$(record), 2)
8170  END IF
8180  RETURN
9000  CLOSE #1
9010  CLOSE #2
9020  CLOSE #3
9030  END
```

APPENDIX C: LOGISTIC MODELS (SAS OUTPUT)

APPENDIX C: LOGISTIC MODELS (SAS OUTPUT)

The SAS System 16:l0 Sunday, April 6, 1997

The LOGISTIC Procedure

Data Set: *WORK NADINE*
Response variable: CODE
Response Levels: 2
Number of Observations: 741
Link Fcnction: Logit

Response Profile

Ordered Value	CODE	Count
1	1	257
2	0	484

Model Fitting Information and Testing global Null Hypothesis BETA=0

Criterion	Intercept *Only*	Intercept and *Covariates*	*Chi-Square* for *Covariates*
AIC	958.574	906.341	
SC	963.182	943.205	
-2 LOG L	956.574	890.341	66.232 with 7 DF (p=0.0001)
Score	.		63.693 with 7 DF (p=0.0001)

Analysis of Maximum Likelihood estimates

Variable	DF	Parameter Estimate	standard Error	Wald Chi-Square	Pr > Chi-square	standardized Estimate	odds Ratic
INTERCPT	1	-2.3287	0.4392	28.1102	0.0001		
CLT	1	0.0272	0.00429	40.0619	0.0001	0.316519	1.028
CAR	1	0.9662	0.4093	5.5728	0.0182	0.243540	2.628
TRK	1	0.4420	0.5051	0.7683	0.3807	0.065611	1.557
SEMI	1	0.7621	0.4408	2.8837	0.0895	0.153311	2.143
WNT	1	-0.4027	0 .1916	4.4200	0.0355	-0.098784	0.668
WKD	1	0.3467	0.1918	3.2685	0.0706	0.083947	1.414
RMPMS	1	-0.2643	0.2098	1.5878	0.2076	-0.059024	0.768

The LOGISTIC Procedure

Association of Predicted Probabilities and Observed Response

```
Concordant = 67.7%          Somers' D = 0.360
Discordant = 31.7%          G   -     = 0.362
Tied       =  0.6%          Tau-a     = 0.163
(124368 pairs)              C         = 0.660
```

The SAS System 16:l0 Sunday April 6, 1997

The LOGISTIC Procedure

Data Set: WORK NADINE
Response Variable: CODE
Response Levels: 2
Number of observations: 741
Link Function: Logit

Response Profile

Ordcrcd Value	CODE	count
1	1	257
2	0	484

Model Fitting Information and Testing gloval Null Hypothesis BETA=0

Criterion	Intercept Only	Intercept and Covariates	Chi-Square for Covariates
AIC	958.574	904.227	
SC	963.182	941.091	
-2 LOG L	956.574	888.227	68.347 with 7 DF (p=0.0001)
Score			65.902 with 7 DF (p=0.0001)

Analysis of Maximum Likelihood Estimates

Variable	DF	Parameter Estimate	Standard Error	Wald Chi-Square	Pr > chi-SqUare	standardized Estimate	odds Ratio
INTERCPT	1	-2.4482	0.4435	30.4735	0.0001		.
CLTWNT	1	0.0177	0.00542	10.6891	0.0011	0.167108	1.018
CLTALL	1	0.0315	0.00471	44.0299	0.0001	0.365366	1.032
CAR	1	0.9646	0.4110	5.5087	0.0189	0.243135	2.624
TRK	1	0.4355	0.5075	0.6703	0.4129	0.061570	1.515
SEMI	1	0.7308	0.4500	2.6374	0.1044	0.147021	2.077
WKD	1	0.3532	0.1926	3.3613	0.0667	0.085517	1.424
RMPMS	1	-0 -2489	0.2090	1.4176	0.2338	-0.055579	0.780

The SA8 System 16:lO Sunday, April 6, 1997

The LOGISTIC Procedure

Association of Predicted Probabilities and Observed Reponses

Concordant	= 68.5%	Somers' D	= 0.376
Discordant	= 30.9%	Gamma	= 0.379
Tied	= 0.6%	Tau-a	= 0.171
(124388 pairs)		c	0.688